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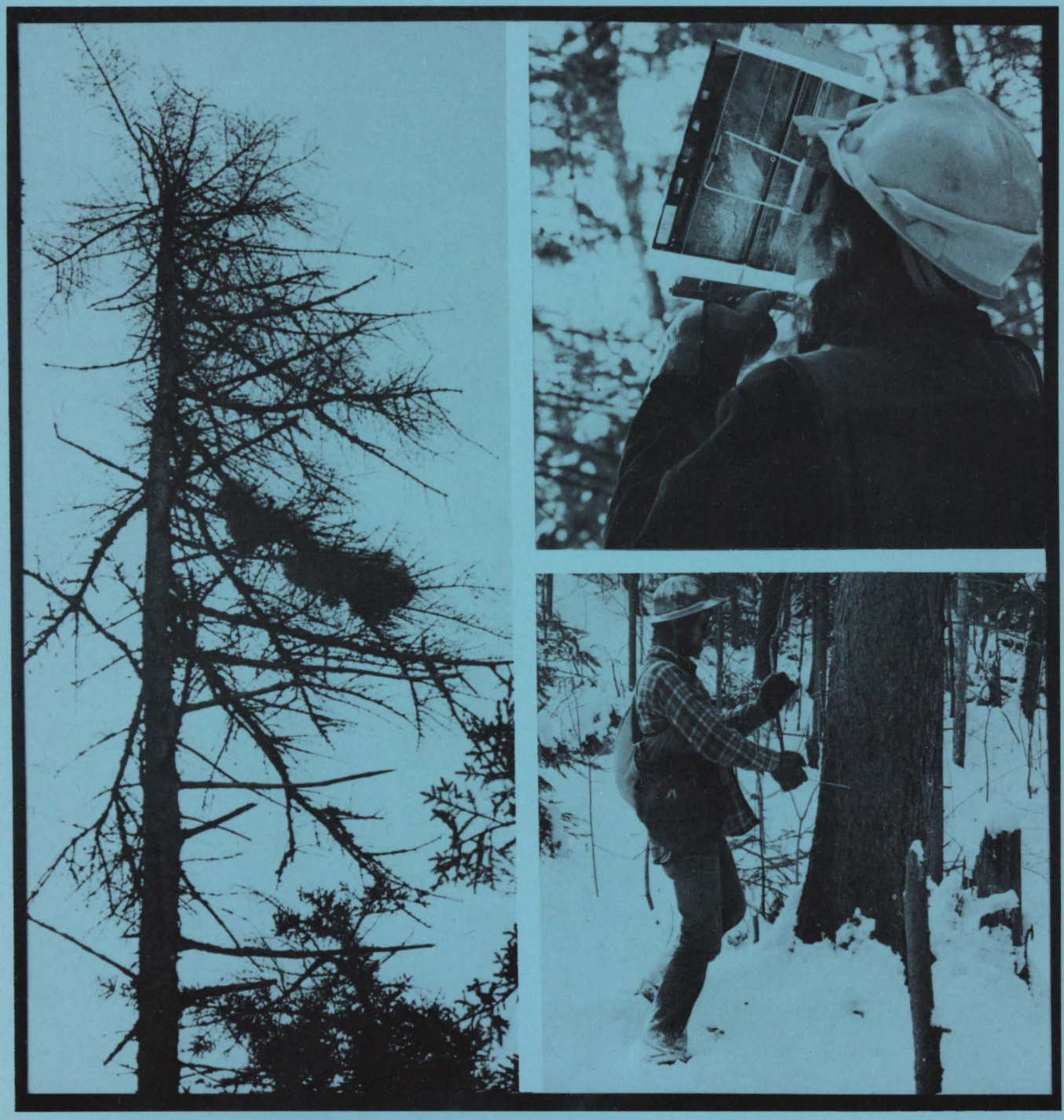
Cooperative Survey of Red Spruce and Balsam Fir Decline and Mortality in New York, Vermont and New Hampshire 1984



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COVER

Left: Red spruce mortality in the White Mountains of New Hampshire.

Upper right: Locating field plots on color infrared photography.

Lower right: Taking an increment core to determine tree age and growth rate.

COOPERATIVE SURVEY OF

RED SPRUCE AND BALSAM FIR DECLINE AND MORTALITY IN NEW YORK, VERMONT AND NEW HAMPSHIRE 1984

Melvyn J. Weiss, Field Representative

Lew R. McCreery, Entomologist

Imants Millers, Entomologist

Margaret Miller-Weeks, Pathologist

James T. O'Brien, Pathologist

Forest Pest Management, Durham Field Office, N. H.

UNITED STATES DEPARTMENT OF AGRICULTURE, FOREST SERVICE, NORTHEASTERN AREA

370 Reed Road, Broomall, Pennsylvania, 19008

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EXECUTIVE SUMMARY

A survey was conducted to determine the extent of tree mortality in the spruce-fir forests of New York, Vermont, and New Hampshire. The USDA Forest Service, Northeastern Area, Forest Pest Management staff, was responsible for the survey. Cooperators were the State forestry agencies of New York, Vermont, and New Hampshire. The survey was conducted from July 1984 to January 1985. Methods used were adapted from previous Forest Pest Management loss assessment surveys.

Four regions were surveyed: Adirondack Region of New York; Tug Hill Region of New York; Vermont; and New Hampshire. The primary objectives of the survey were to determine for each region:

- The proportion of the spruce-fir slope and mixedwood cover types classified with light (less than 10 percent), moderate (10 to 30 percent), and heavy (more than 30 percent) cumulative mortality.
- The number and volume of dead and declining spruce and balsam fir.
- Spruce and fir regeneration stocking.

Adirondack Region

Mortality Area

The percentage of the spruce-fir slope type in each mortality class was:

light	41	(86,500 acres)
moderate	31	(65,400 acres)
heavy	28	(58,100 acres)

The percentage of mixedwood type in each mortality class was:

light	56	(254,600 acres)
moderate	33	(149,700 acres)
heavy	11	(50,500 acres)

Dead and Declining Trees

In the spruce-fir slope type, the percentage of dead spruce per acre, excluding snags and windthrow, in each mortality class was:

light	6.8	(5.6 trees per acre)
moderate	18.6	(17.7 trees per acre)
heavy	15.8	(14.9 trees per acre)

In the mixedwood type, the percentage of dead spruce per acre, excluding snags and windthrow, in each mortality class was:

light	12.3	(7.1 trees per acre)
moderate	8.6	(3.3 trees per acre)
heavy	16.9	(10.5 trees per acre)

In the spruce-fir slope type, the percentage of dead balsam fir per acre, excluding snags and windthrow, in each mortality class was:

light	8.2	(4.8 trees per acre)
moderate	6.7	(4.1 trees per acre)
heavy	5.8	(3.4 trees per acre)

In the mixedwood type, the percentage of dead balsam fir per acre, excluding snags and windthrow, in each mortality class was:

light	10.0	(3.6 trees per acre)
moderate	9.0	(3.7 trees per acre)
heavy	6.3	(1.5 trees per acre)

The highest percentage (14.9) of live spruce rated as severely declining was in the moderate-mortality class of the mixedwood type. The highest percentage (6.8) of live balsam fir rated as severely declining was in the light-mortality class of the mixedwood type. The symptoms most frequently recorded for trees rated as severely declining were small dead branches, loss of foliage from the outside in, chlorotic foliage, and necrotic foliage. These symptoms may be associated with any of a large number of factors such as drought, diseases, insect damage, and competition.

Regeneration Stocking

In the spruce-fir slope type, the percentage of regeneration stocking, including both spruce and balsam fir, by mortality class was:

light	61.2
moderate	62.9
heavy	78.0

In the mixedwood type, the percentage of regeneration stocking, including both spruce and balsam fir, by mortality class was:

light	52.4
moderate	54.1
heavy	80.4

Tug Hill Region

Mortality Area

The percentage of the spruce-fir slope type in each mortality class was:

light	100	(9,100 acres)
moderate	--	
heavy	--	

The percentage of the mixedwood type in each mortality class was:

light	82	(10,900 acres)
moderate	16	(2,200 acres)
heavy	2	(200 acres)

Dead and Declining Trees

In the spruce-fir slope type, the percentage of dead spruce per acre, excluding snags and windthrow, in each mortality class was:

light	13.4	(3.4 trees per acre)
moderate	--	
heavy	--	

In the mixedwood type, the percentage of dead spruce per acre, excluding snags and windthrow, in each mortality class was:

light	15.0	(9.6 trees per acre)
moderate	10.4	(5.7 trees per acre)
heavy	11.4	(6.6 trees per acre)

In the spruce-fir slope type, the percentage of dead balsam fir per acre, excluding snags and windthrow, in each mortality class was:

light	14.9	(19.1 trees per acre)
moderate	--	
heavy	--	

In the mixedwood type, the percentage of dead balsam fir per acre, excluding snags and windthrow, in each mortality class was:

light	11.2	(11.9 trees per acre)
moderate	9.6	(11.5 trees per acre)
heavy	17.7	(9.3 trees per acre)

The highest percentage (58.9) of live spruce rated as severely declining was in the heavy-mortality class of the mixedwood type. The highest percentage (19.4) of live balsam fir rated as severely declining was in the heavy-mortality class of the mixedwood type. The symptoms most frequently recorded for trees rated as severely declining were small dead branches, chlorotic foliage, loss of foliage from the inside out (balsam fir only), and necrotic foliage.

Regeneration Stocking

In the spruce-fir slope type, the percentage of regeneration stocking, including both spruce and balsam fir, by mortality class was:

light	25.6
moderate	--
heavy	--

In the mixedwood type, the percentage of regeneration stocking, including both spruce and balsam fir, by mortality class was:

light	38.4
moderate	46.4
heavy	26.0

Vermont Region

Mortality Area

The percentage of the spruce-fir slope type in each mortality class was:

light	78	(103,000 acres)
moderate	13	(17,200 acres)
heavy	9	(12,400 acres)

The percentage of the mixedwood type in each mortality class was:

light	83	(99,000 acres)
moderate	14	(17,000 acres)
heavy	3	(3,900 acres)

Dead and Declining Trees

In the spruce-fir slope type, the percentage of dead spruce per acre, excluding snags and windthrow, in each mortality class was:

light	4.6	(3.2 trees per acre)
moderate	6.1	(7.3 trees per acre)
heavy	12.1	(14.0 trees per acre)

In the mixedwood type, the percentage of dead spruce per acre, excluding snags and windthrow, in each mortality class was:

light	6.5	(3.5 trees per acre)
moderate	7.6	(4.5 trees per acre)
heavy	25.3	(4.0 trees per acre)

In the spruce-fir slope type, the percentage of dead balsam fir per acre, excluding snags and windthrow, in each mortality class was:

light	2.5	(1.0 trees per acre)
moderate	9.4	(5.0 trees per acre)
heavy	14.4	(9.1 trees per acre)

In the mixedwood type, the percentage of dead balsam fir per acre, excluding snags and windthrow, in each mortality class was:

light	24.4	(2.2 trees per acre)
moderate	4.2	(1.3 trees per acre)
heavy	17.1	(11.9 trees per acre)

The highest percentage (18.0) of live spruce rated as severely declining was in the heavy-mortality class of the mixedwood type. The highest percentage (6.8) of live balsam fir rated as severely declining was in the heavy-mortality class of the spruce-fir slope type. The symptoms most frequently recorded for trees rated as severely declining were small dead branches and loss of foliage from the outside in.

Regeneration Stocking

In the spruce-fir slope type, the percentage of regeneration stocking, including both spruce and balsam fir, by mortality class was:

light	31.2
moderate	41.9
heavy	63.8

In the mixedwood type, the percentage of regeneration stocking, including both spruce and balsam fir, by mortality class was:

light	20.0
moderate	39.2
heavy	47.7

New Hampshire Region

Mortality Area

The percentage of spruce-fir slope type in each mortality class was:

light	42	(73,400 acres)
moderate	15	(25,600 acres)
heavy	43	(76,300 acres)

The percentage of the mixedwood type in each mortality class was:

light	61	(104,500 acres)
moderate	12	(21,300 acres)
heavy	27	(45,900 acres)

Dead and Declining Trees

In the spruce-fir slope type, the percentage of dead spruce per acre, excluding snags and windthrow, in each mortality class was:

light	8.6	(14.4 trees per acre)
moderate	8.0	(10.6 trees per acre)
heavy	14.0	(14.6 trees per acre)

In the mixedwood type, the percentage of dead spruce per acre, excluding snags and windthrow, in each mortality class was:

light	7.8	(7.7 trees per acre)
moderate	10.0	(3.7 trees per acre)
heavy	26.1	(13.0 trees per acre)

In the spruce-fir slope type, the percentage of dead balsam fir per acre, excluding snags and windthrow, in each mortality class was:

light	6.5	(6.8 trees per acre)
moderate	12.1	(8.7 trees per acre)
heavy	5.2	(10.2 trees per acre)

In the mixedwood type, the percentage of dead balsam fir per acre, excluding snags and windthrow, in each mortality class was:

light	4.6	(5.2 trees per acre)
moderate	8.9	(8.2 trees per acre)
heavy	10.3	(14.7 trees per acre)

The highest percentage (21.1) of live spruce rated as severely declining was in the moderate mortality class of the mixedwood type. The highest percentage (2.3) of the balsam fir rated as severely declining was in the heavy-mortality class of the spruce-fir slope type. The symptoms most frequently recorded for trees rated as severely declining were small dead branches, large dead branches, and loss of foliage from the outside in.

Regeneration Stocking

In the spruce-fir slope type, the percentage of regeneration stocking, including both spruce and balsam fir, by mortality class was:

light	62.4
moderate	61.1
heavy	81.7

In the mixedwood type, the percentage of regeneration stocking, including both spruce and balsam fir, by mortality class was:

light	64.8
moderate	76.5
heavy	78.8

All Regions

Mortality Area

The extent of light, moderate, and heavy mortality varied among regions. These differences probably are related to forest age, soil, and elevation. Intensive examination is needed in areas classified as having moderate or heavy mortality to determine what factors may be involved and to what extent the mortality may be considered normal.

Dead and Declining Trees

Cover types and mortality classes with higher percentages of dead trees need to be examined for all factors that could explain the higher mortality. Further examination is needed to determine the primary cause of damage in trees rated as declining.

Regeneration Stocking

Except for Tug Hill, regeneration stocking was highest in the heavy mortality class for both spruce-fir slope and mixedwood types. This indicates that as overstory trees die, the stands are being restocked. Areas with heavy mortality need to be examined periodically to determine the long-term success of established regeneration.

Interpreting the Data

The mortality classes used in the survey do not necessarily indicate increasing rates of current mortality or the extent of any abnormal conditions. The assumption was that up to 10 percent standing dead trees represent a normal forest condition. One to three percent annual mortality has been recorded in inventories of commercial forests in New York, Vermont, and New Hampshire since the 1940's. This mortality is due to such factors as competition and chronic insect and disease damage. Dead trees usually remain standing for 5 years or longer. Therefore, 10 percent cumulative standing mortality can be considered the normal condition. Many high-elevation, noncommercial stands were included in the survey. In these stands, normal cumulative mortality may be considerably greater than 10 percent because the rate at which dead trees deteriorate is slower than at lower elevations. No comparable data were collected previously, so the trend in mortality area cannot be determined without follow-up surveys. However, the data collected do provide indications of past trends in tree mortality and regeneration.

The survey was not designed to provide the location of all areas of moderate or heavy mortality. Location of mortality was determined in sample blocks only. Because both commercial and noncommercial areas were included in the survey regions, and because an undetermined amount of the mortality is normal, economic losses are not as great as might be indicated by the data alone. Assessment of economic loss will not be possible without additional work.

The data presented are estimates for each region and are based on samples. The estimates are most precise at the survey region level. They are not necessarily applicable to a smaller unit. The survey was not designed to provide estimates for specific ownerships or management units.

Red spruce was the predominant spruce in both the spruce-fir slope and mixedwood cover types. White spruce and black spruce were minor components except in Vermont, where white spruce made up about 18 percent of the live spruce basal area and 6 percent of the dead spruce basal area.

Determining the cause or causes of mortality was not an objective of the survey, though historical records of mortality and major mortality factors were reviewed. Detailed examination of specific situations will be needed to determine the incidence of historically significant insects and diseases, and the extent to which they are responsible for the mortality observed.

Past Records of Mortality

Historical records were searched for previous reports of mortality and its causes. Competition and chronic insect and disease damage have caused mortality annually. The spruce budworm has been a serious problem in recent years in northern New Hampshire and northeastern Vermont. Areas known to have spruce budworm damage were not included in the survey. Several other factors have been reported causing damage and mortality in one or more of the regions in recent years.

At high elevations:

- Wind, ice, and snow
- Winter desiccation
- Drought
- Overmature stand conditions
- Fluctuations in water level

At low elevations:

- Drought
- Winter desiccation
- The spruce beetle (spruce more than 10 inches d.b.h.)
- Root diseases
- Fluctuations in water level

Change in climate is another factor that has been discussed in relation to tree mortality at both high and low elevations. Air pollution also has been suggested as a factor that may be involved.

Recommendations

Forest Pest Management surveys and evaluations are recommended to determine:

- The major relationships between mortality and a large range of site and stand conditions.
- The role of historically significant insects and diseases in areas of moderate to heavy mortality.
- Increases in the extent and rate of mortality.
- The location of areas on state and private lands where mortality is occurring.
- The precise delineation and classification of mortality areas on the National Forests.
- The economic impact of the moderate and heavy mortality.

INTRODUCTION

In the Northeast, extensive mortality of red spruce, Picea rubens Sarg., and balsam fir, Abies balsamea (L.) Mill., has occurred several times during the last two centuries. The most important causes of mortality have been fire, the spruce beetle, Dendroctonus rufipennis (Kirby), (Westveld 1953), and the spruce budworm, Choristoneura fumiferana (Clem.), (Hopkins 1901). The spruce beetle and fire killed vast numbers of trees at various times during the 19th century. In recent years, the spruce beetle has caused tree mortality in New York (USDA Forest Service 1985). The spruce budworm killed large numbers of trees during several outbreaks. Recently, it caused significant mortality in northern New Hampshire, northeastern Vermont, and Maine (Kucera and Taylor 1984).

While most historical records were concerned with these major mortality factors, other causes also were reported. In the early 1950's, red spruce mortality on the Green Mountain National Forest in Vermont was attributed to a combination of old age and severe growing conditions (Mook and Eno 1956). At about the same time, winter injury and drought led to mortality of spruce and balsam fir in the Adirondacks (Curry and Church 1952).

Through the 1960's, mortality of red spruce and balsam fir was reported at several locations in New York, Vermont and New Hampshire [1,2,3,4] (Ford 1969; Ford and Murray 1966; Hadfield 1968a, 1969a,b; Siccama 1974; USDA Forest Service 1970a; Vermont Department of Forests and Parks 1960, 1962, 1966). Major factors were thought to be drought and winter injury. Root disease was associated with mortality on some sites.

Reports of damage and mortality continued into the 1970's and 1980's [5,6,7] (Allison 1975; Friedland and others 1984; Johnson and Siccama 1983; Siccama and others 1982; Snowden 1972; Sprugel 1976; USDA Forest Service 1973).

Effects of long-term changes in climate and of man's activities could be important. Griggs (1946) suggested that changes observed in high-elevation stands of red spruce and balsam fir in New Hampshire during the 1930's and 1940's were related to climatic change. Vulnerability of red spruce at lower elevations to climatic change was discussed by Siccama (1974) in relation to mortality observed from 1963 to 1965 at Camel's Hump in Vermont. Wright (1955) pointed out the limited genetic adaptability of red spruce and possible implications of change in climate. Others have discussed how man's activities have affected forest quality (Westveld 1953). Cronon (1983) reviewed the effect of man's activities in relation to the New England forests beginning in the colonial period.

Mortality of red spruce and balsam fir in New York, Vermont, and New Hampshire has received increased attention following reports by Vogelmann (1982) and Johnson and Siccama (1983). Vogelmann reported on red spruce mortality on Camel's Hump and discussed possible causes, including acid rain. Johnson and Siccama reported that on seven study sites in New York, Vermont, and New Hampshire, reductions in basal area of some size classes of red spruce were substantial between the mid-1960's and late 1970's. The basal area of balsam fir also was reduced in some size classes at the same sites, but to a lesser extent. Johnson and Siccama also discussed possible causes, including drought and acid rain.

Because of increasing concern about the red spruce and balsam fir resource, the USDA Forest Service's Forest Pest Management staff and the State forestry agencies of New York, Vermont, and New Hampshire conducted a survey in 1984 to determine the extent of tree mortality over the range of the spruce-fir type in the three States. Under authority of the Cooperative Forestry Assistance Act of 1978, the USDA Forest Service is responsible for assessing the effects of damage from insects and diseases and from abiotic agents on the Nation's forest resources. This responsibility is carried out directly on Federal lands and through the State Foresters on State and private lands.

The survey was designed to provide information on the extent of tree mortality and regeneration for the Adirondack Mountains of New York, the Tug Hill Plateau of New York, the Green Mountains of Vermont, and the White Mountains of New Hampshire. Maine and those parts of the spruce-fir type in New Hampshire and Vermont affected by the recent spruce budworm outbreak were excluded. All ownerships were included in the survey regions, including the White and Green Mountain National Forests.

The primary objectives of the survey were to determine for each of the four regions:

1. The proportion of mortality in the spruce-fir slope and mixedwood cover types. Mortality was classed as light (less than 10 percent); moderate (10 to 30 percent); or heavy (more than 30 percent).

2. The number and volume of dead, declining, and healthy trees.

3. The proportion of the spruce-fir and mixedwood types adequately stocked with spruce or other commercial species.

A secondary objective was to provide a baseline of the extent of mortality to be used to determine trends over time. Other objectives of the survey were to record site factors such as elevation and aspect, stand factors such as age and condition of trees, and the presence of readily identifiable insect or disease agents that were associated with dead and declining trees.

The first phase of the survey, acquisition and interpretation of aerial photographs, was conducted from July to November in 1984. Collection of ground plot data began in September and was completed in January 1985.

This survey was a cooperative effort among the USDA Forest Service, Northeastern Area; the New York State Department of Environmental Conservation, Division of Lands and Forests; the Vermont Department of Forests, Parks and Recreation, Division of Forests; and the New Hampshire Department of Resources and Economic Development, Division of Forests and Lands. The State agencies helped plan the survey and collected much of the field data.

Forest Pest Management's Methods Application Group provided the basic survey design and flew the photo mission. The Nationwide Forestry Applications Program of the USDA Forest Service was responsible for photo interpretation. Some photo interpretation also was done by the Forest Pest Management staff, Durham, New Hampshire. The Northeastern Forest Experiment Station participated on the steering committee for the survey. The White and Green Mountain National Forests also participated on the steering committee and provided logistical support to the field crews.

HISTORY OF DAMAGE

Discolored, dying, and dead spruce and balsam fir have been reported sporadically over the last two centuries. The old-growth spruce was attacked by the spruce beetle. The mature spruce-fir forests were decimated by the spruce budworm. Insect pests and human activities such as logging, agriculture, and fire have changed much of the forest from predominantly spruce to mostly hardwoods. Today, red spruce is predominantly in high elevations on exposed and poor sites, not because these areas are best suited for its growth, but because these sites are less favorable for its competitors (Hart 1959a). Mortality of red spruce is most likely in older forests, after trees reach 10 inches in diameter at breast height (d.b.h.), and in the very shallow soils in the upper elevations where the trees are exposed to short growing seasons and adverse climatic conditions. Biological agents likely are the primary cause of death of large and mature spruce and balsam fir. Weather extremes are more likely to limit the growth of spruce and fir at high-elevation sites.

Causal Agents

Insect outbreaks weaken trees and can cause mortality over large areas. The greatest damage to spruce and balsam fir has been caused by the spruce beetle and the spruce budworm. Insect-caused mortality usually is sporadic approaching cyclic.

Diseases cause some damage every year; such damage may intensify when trees are weakened by other factors such as defoliation, drought, wind breakage, and competition. Mortality from wind, low temperature, and moisture fluctuations occurs almost every year at higher elevations and occasionally at lower elevations.

Mammals and birds occasionally kill trees or damage them. Beavers cause flooding, porcupines girdle upper crown stems, and grosbeaks remove upper crown buds and deform the crown.

Long-range atmospheric deposition of harmful chemicals has been suggested as a potential cause of tree damage, though no cause-effect relationship has been established. It has been suggested that such damage is most likely at higher elevations, where trees are most exposed to prevailing winds.

Often, it is difficult to identify the causal agent or agents. Discolored foliage, reduced growth, and branch and tree mortality may be related to a single agent or to multiple damage agents acting in any one year or over a period of years.

Insect Pests

Spruce budworm.--Outbreaks of the spruce budworm, Choristoneura fumiferana (Clem.), have been traced in North America for several centuries (Blais 1965). Outbreaks occur about twice in a century, causing the death of millions of trees. Predominance of mature spruce and balsam fir forests appears to be a prerequisite for outbreak development. Northeastern Vermont, northern New Hampshire, and most of Maine are within the current budworm outbreak area (Kucera and Taylor 1984).

Spruce beetle.--The spruce beetle, Dendroctonus rufipennis (Kirby), has killed millions of board feet of red spruce (Hopkins 1901). Vast outbreaks occurred until the beginning of the 20th century, but since have dwindled to several outbreaks covering a few thousand acres.

Balsam woolly adelgid.--The balsam woolly adelgid, Adelges piceae (Ratz.), an introduced pest, once threatened the northeastern balsam fir forests (Ford 1969). It is active in eastern Maine, but populations have declined in the colder inland and mountainous regions.

Eastern hemlock looper.--The eastern hemlock looper, Lambdina fiscellaria fiscellaria (Guen.), occasionally defoliates balsam fir, but extensive areas of tree mortality have not been reported (Baker 1972).

Black-headed budworm.--Outbreaks of the black-headed budworm, Acleris variana (Fern.), have occurred in the spruce-fir forests, but extensive tree mortality has not been reported (Baker 1972).

Sawflies.--Sawflies occasionally defoliate stands of red spruce. The European spruce sawfly, Diprion hercyniae (Hartig), and the yellowheaded spruce sawfly, Pikonema alaskensis (Roh.), are the most common sawflies attacking spruce (Baker 1972).

Ghost moth.--The ghost moth, Hepialus gracilis Grote, was reported in large numbers in a spruce mortality area on Camel's Hump (Siccama and others 1982). Biological investigations have confirmed the presence of the insect and discovered root damage, though a cause-effect relationship has not been determined.[8]

Diseases

A thorough review of literature on diseases of spruces and balsam fir is presented by Hepting (1971). Included here are only those diseases that might be involved in large areas of stand deterioration.

Trunk and butt rots.--The most common trunk rot of balsam fir is caused by the fungus Haematostereum sanguinolentum (Alb. and Schw.: Fr.) Pouz. (Hepting 1971). It causes 90 percent of all the trunk rot in balsam fir. Trunk and butt rots play a major role in high cull in balsam fir as trees approach 70 to 80 years of age (Hepting 1971). Trunk and butt rots occur so frequently in balsam fir that this species usually is managed on a pathological rotation age of about 50 years on poorer sites and about 70 years on better sites (Blum and others 1983). Two important diseases of spruce are red ring rot, Phellinus pini (Thore.: Fr.) Pilát, and red brown butt rot, Phaeolus schweinitzii (Fr.) Pat.

Root rots.--Shoestring root rot, caused by Armillaria mellea (Vahl: Fr.) Kummer, is commonly associated with deterioriating spruce in lower elevations, but is not frequent in high-elevation deteriorating stands (Carey and others 1984). Shoestring root rot is considered the most important killing disease of balsam fir (Hepting 1971).

Stem diseases.--In general, stem diseases do not cause major damage in red spruce or balsam fir. Trunk cankers on spruce, caused primarily by Valsa kunzei Fr. var. piceae Waterm., produce copious resin flow (Hepting 1971). Eastern dwarf mistletoe, Arceuthobium pusillum Peck, is common on spruce throughout New England and New York (Hawksworth and Weins 1972). Hawksworth and Shigo (1980) found that A. pusillum not only occurs on red spruce in parts of the White Mountains of New Hampshire, but also causes growth loss, butt log degrade, and mortality; damage is most prevalent on trees 100 or more years old. On balsam fir, three major stem diseases capable of causing dieback are caused by Valsa kunzei Fr., Thyronectria balsamea (Cke. and Pk.) Seeler, and Dermea balsamea (Pk.) Seav. (Hepting 1971).

Foliage diseases.--Balsam fir is damaged by many foliage diseases but none affects wood production. The main foliage diseases of red spruce are rusts caused by six species of Chrysomyxa. In addition, two needlecast fungi are known to severely defoliate understory spruce and the lower branches of larger trees (Hepting 1971).

Fire

Fire is a component of the northern conifer ecosystem but intervals between fires in the Northeast generally are more than 100 years (Heinselman 1978). The major changes in fire frequency and intensity came with logging and agriculture in the 1800's and early 1900's. After areas were logged and burned; hardwoods dominated the new forest. In many areas, fires were used to clear the land for agriculture. When these lands were abandoned, many converted to hardwoods. Thus, the combination of agriculture, logging, and fire probably is responsible for the conversion of prime spruce forests on the hillsides to hardwoods (Oosting and Billings 1951; Westveld 1953). Many of today's spruce stands are at high elevations, growing in adverse conditions only because spruce survive there better than other species (Hart 1959a). At the same time, many mountaintops are bare of trees after fires removed the old stands and all of the humus (Baldwin 1977). Many years will be needed for these sites to rebuild to where spruce can grow again.

Wind

Wind affects both red spruce and balsam fir. The shallow-rooted spruce are easily windthrown (Graves 1899; McLintock 1954). Windthrow and windbreakage also are common for balsam fir (Behre 1921; Hart 1959b; Zon 1914). At high elevations, tree crowns are shaped by the prevailing high winds (Ketchledge 1984). The trees are short, with most branches low on the stem. Hurricanes have destroyed large stands of spruce and balsam fir, as well as other tree species (Natti 1979). Damage occurs at high elevations when winds whip trees laden with rime ice (Griggs 1946).

The impact of wind on balsam fir was recognized by Chittenden (1905), who stated that balsam fir is easily windthrown. He observed that, at high elevations, the constant swaying of the tree in the wind may sever the connection of the rootlets, breaking and tearing them; as a result, the tree gradually dries out and dies for no apparent reason. "Often large areas of such dead and dying trees are found on the upper slopes," he concluded. Stone (1977) describes root damage from wind-caused root movements in rocky soils in the Adirondacks.

Winter Injury

Discoloration of foliage observed during winter or early spring is ascribed to winter injury (Sakai 1970). At high elevations, the mere reduction in the length of the growing season reduces tree growth (Ketchledge 1984). Mortality of buds from temperature fluctuations in winter has caused branch and tree mortality. Desiccation of buds on the windward side of trees is the major factor responsible for the "flagging" at high elevations (Holroyd 1970). The loss of needles and buds occurs when shoots are ripped off by wind after ice buildup, resulting in mortality of balsam fir on the exposed edges of regeneration waves (Ketchledge 1984; Marchand 1984).

Sakai and Otsuka (1970) presented data that showed the need for cold hardening of trees. They found that even during the winter, temperature fluctuations above and below freezing associated with drying conditions can cause damage. Griggs (1946) noted that rime ice is frequent at high elevations on Mount Washington in New Hampshire, and that such icing accompanied by high winds is extremely

damaging to trees. The possibility of nutrient increase, particularly nitrogen, has been suggested as a factor predisposing trees to winter injury (Friedland and others 1984). Reduced root development from winter injury has been observed in black spruce seedlings (Colombo and Glerum 1984). This also may occur on red spruce in winter-damage areas, possibly limiting the growth of red spruce or even killing it.

Reiners and Lang (1979) discussed various processes at work in the upper-elevation fir zone in the White Mountains of New Hampshire. They discussed fir waves as described by Sprugel (1976) and Sprugel and Bormann (1981), and in addition, described broken tree gaps, strips, and glades. Broken tree gaps composed of pistol-butted, broken, and down trees are thought to be caused by the weight of heavy snow packs or rime ice. Strips are likened to fir waves but have a more irregular pattern. The dieback fronts of the strips appear to increase in number with elevation. Glades are areas on the lee slopes where deep snowbanks occur, and where regeneration is lacking. Reiners and Lang suggested that their findings, with local modifications, would apply to a broader region, including the Green Mountains of Vermont and Adirondack Mountains of New York.

Water Deficit

Red spruce and balsam fir grow best in well-drained soils, with a high water-holding capacity and a thick layer of humus (Frank and Bjorkbom 1973; Murphy 1917). The spruce-fir forests are predominantly in regions of high rainfall in the Northeastern United States (Blum and others 1983). However, as mentioned previously, many red spruce and balsam fir stands in mountainous regions are relegated to high-elevation shallow soils where they grow better than other species (Hart 1959a). During periods of drought, water deficits might appear here before they occur in other areas where soil water reserves are more abundant. Drought is frequently reported as a major cause of tree mortality.

Siccama (1974) discussed a possible relationship of red spruce mortality with drought at lower elevations on Camel's Hump in the 1960's. Spurr (1964) noted that fir is more tolerant of warmer and drier climates than spruce. Similar observations are reported from the Catskills in New York (McIntosh and Hurley 1964), Camel's Hump (Siccama 1974), and Ontario, Canada (Place 1955).

Another kind of damage associated with water deficit is known as winter drying or desiccation. When upper parts of the tree become active from warming winds or solar radiation while lower parts (below snow) remain frozen, foliage burn, or browning, occurs (Baldwin 1977; Kozlowski 1976; Sakai 1970). Although the symptoms are not disputed, the "drying" theory is contradicted by Kincaid and Lyons (1981), who were unable to demonstrate excessive water deficits in foliage or small twigs.

Flooding

Although spruce and balsam fir grow on wet sites, trees are killed by sudden elevation of the water table and submersion of the roots. Beaver dams are the most common cause of flooding; though human activities also can cause flooding. Dams built in lowlands to develop water reservoirs may kill large areas of trees. Road construction may build up local water tables, or prevent normal drainage and aeration of water, causing tree mortality (Blanchard and Tattar 1981).

Climate

Hepting (1963) discussed the role of climate as a cause of forest declines. In reviewing evidence on climatic change in New England and the Northeast, Spurr (1964) found that a general warming trend has occurred since the early to mid-1800's. He suggested that the temperature difference could account for the frequent poor vigor of southern outliers of tree species, and the healthy condition of other tree species thriving north of their common range. Siccama (1974) discussed how even a slight change in climate might affect species composition on southwest-facing slopes of Camel's Hump, and noted the high mortality of red spruce as a possible indication of such a change.

The possibility of long-term climatic change also was raised by Griggs (1946). After a decade of study, he concluded that the balsam fir near timberline in the Presidential Range of New Hampshire were "losing ground." Poor condition of present trees, and their small size compared to the remains of former trees, was seen as evidence of "forest deterioration and of recession by timberline."

Long-term adaptability of red spruce to climatic or site change is an important factor. Wright (1955), based on personal communication with Westveld, stated that in Eastern North America, red spruce is losing ground with respect to its range, whereas the range of white spruce is expanding. Wright pointed out that red spruce is at a disadvantage because of genetic uniformity; he suggested that many of the red spruce stands situated near mountaintops would be "exterminated" and that a great part of genetic variability would be destroyed during a warm period.

Air Pollution

In recent years, atmospheric deposition has received increasing attention as a possible factor contributing to tree stress. The

long-range transport of sulfur compounds and the increased acid deposition along prevailing cyclonic paths in the Northeast were discussed by Likens and others (1972) and Johnson and others (1972). The major findings presented at the First International Symposium on Acid Precipitation and the Forest Ecosystem in 1975 indicated that acid precipitation is increasing in the Northeastern United States and that the possible effects on the forest ecosystem should be investigated (Dochinger and Seliga 1976).

Vogelmann (1982) reported on red spruce mortality on Camel's Hump and discussed possible causes, including acid rain. However, after a review of various other studies, Hansen (1983) concluded that the extreme drought occurring in the mid-1960's probably initiated the mortality observed on Camel's Hump. Johnson and Siccama (1983) reviewed the implications of acid deposition and forest decline in high-elevation spruce and fir forests. They concluded that many circumstances point to the adverse effects of acid deposition, possibly causing the observed spruce decline in certain study sites in New Hampshire, New York, and Vermont. The possible effects of excessive nitrogen on winter hardening of spruce foliage were discussed by Friedland and others (1984).

The College of Environmental Science and Forestry, State University of New York, examined the literature concerning acidic deposition and dieback of red spruce in the Northeast (Burgess 1984). It concluded that the direct or most probable cause of dieback has not been identified, and that multiple causal agents probably are involved.

In comparing vegetation changes in a Mount Marcy alpine meadow between 1957 and 1981, Ketchledge and Leonard (1982) concluded that "this most fragile of all ecosystems in New York State has escaped the postulated damage (acid rain) widely heralded elsewhere about these mountains."

In reviewing the effects of air pollution on forests, Smith (1981) concluded that acid precipitation and heavy metals in the boreal and northern forests are cause for concern. Regarding foliar damage to trees from atmospheric pollutants, he stated: "It is further important to recognize that the symptoms of acute foliar response to air pollutants are not unlike the symptoms induced in tree foliage by a host of other abiotic and biotic stress factors. The diagnosis of specific tree responses to air pollution stress will involve the same care, knowledge, and perspective that all woody plant diagnoses involve; that is, a good appreciation of all stress factors, and the symptoms they cause, for a given plant in a given location. It will further be necessary to have some appreciation of the historical stresses that have impacted the tree in order to make an accurate diagnosis."

Past Records of Mortality

The following historical record of insect, disease, and abiotic damage to red spruce and balsam fir forests was obtained from survey records over the past two centuries. Most of the recent records are the result of periodic, routine aerial and ground detection surveys completed by USDA Forest Service and State forest pest management specialists.

Although Maine was not included in the survey being reported here, historical records of damage and mortality in Maine are useful for a better understanding of the problems that affect the growth of spruce and balsam fir.

Maine

1984.--The spruce budworm outbreak is in its 35th year. Tree mortality is common throughout the State. The recent history of the spruce budworm outbreak was summarized by Pistell and Harshberger (1979) and Weed (1977). The impact of the budworm on Maine's forests was reported by Schiltz and others (1983).

During an aerial survey by Forest Pest Management in 1984, most of the balsam fir in the Baxter State Park were found dead. The lower elevation balsam fir probably were killed by the spruce budworm. However, another agent may be involved at higher elevations as the budworm usually does not cause damage above 2,300 feet.

1976.--Balsam fir mortality in narrow bands in high elevations of Baxter State Park was described by Sprugel (1976). These fir, or regeneration waves, are interpreted as a normal ecological process with tree mortality caused by removal of foliage by ice and wind action (Marchand 1984).

1910-18.--Millions of cords of spruce and balsam fir were killed by the spruce budworm throughout the spruce-fir region (Weed 1977).

1901.--Extensive mortality of red spruce in the Androscoggin headwaters region (Hopkins 1901), was caused by the spruce beetle.

Late 1870's.--Spruce and balsam fir mortality from spruce budworm was reported by Johannsen (1913). He refers to Professor A. S. Packard describing large areas of killed trees along the coastal area from Portland east to the New Brunswick border.

1874-81.--Spruce beetle outbreaks were reported in northwestern Maine (Hopkins 1901). More than 1 million board feet of spruce were reported killed along the Allagash and St. John Rivers.

1818.--Hopkins (1901) reported an extensive insect outbreak, resulting in tree mortality east of the Penobscot River. The spruce beetle was suspected.

1807.--Johannsen (1913) and Hopkins (1901) reported an outbreak at Harpswell. Johannsen suggested that the cause was spruce budworm, while Hopkins suspected the spruce beetle.

New Hampshire

1984.--About 63,500 acres of spruce and balsam fir with average mortality exceeding 10 percent were mapped during an aerial survey of the White Mountain National Forest.[5] About 60 percent of the mortality area was at elevations above 3,000 feet. This mortality was observed in previous aerial surveys and apparently was in progress for about two decades. Spruce budworm-caused mortality is continuing in northern Coos County (USDA Forest Service 1985).

1982.--Mortality of red spruce was reported at Hubbard Brook (Johnson and Siccama 1983). They indicated that about half of the spruce had died in the last 10 years. On the basis of similar observations at other sites, they concluded that "spruce decline" is intensifying.

1980.--Hawksworth and Shigo (1980) found that eastern dwarf mistletoe, Arceuthobium pusillum, not only occurs on red spruce in parts of the White Mountains, but also causes growth loss, butt-log degrade, and mortality. Damage is most prevalent on trees 100 or more years old.

1978.--Spruce and fir mortality was reported at elevations exceeding 3,500 feet in the Presidential Range, Great Gulf Wilderness, Dartmouth Range, Sandwich Range, and Pilot Range.[6] On the basis of previous reports, the mortality was attributed to drought, old age, and poor site. Fir trees killed by the balsam woolly adelgid were also reported in small isolated pockets.

1970's.--Scattered pockets of dead and dying balsam fir were reported by USDA Forest Pest Management staff on the White Mountain National Forest (Snowden 1972; USDA Forest Service 1973.) The mortality was attributed to the balsam woolly adelgid. A spruce budworm outbreak began in the mid-1970's and by 1980 had created areas of dead spruce and balsam fir in Coos County (Avery 1976; Kucera and Taylor 1984). Bands of dead balsam fir were observed by Sprugel (1976) in the higher elevations of the Presidential Range. He concluded that this wave-like mortality is a normal and continuous regeneration process.

1968.-- Winter injury caused browning of spruce and fir on 10,000 to 15,000 acres at higher elevations (Hadfield 1969b). Buds were not killed.

1960's.--Almost annual concern was expressed over dying spruce and balsam fir in higher elevation stands. The mortality apparently started with 1962-63 winter kill caused by high winds and extreme cold around New Year's,[1] The mortality continued for several years [2,3,4] (Ford 1969; Ford and Murray 1966; Hadfield 1968b, 1969a; USDA Forest Service 1970a,b). No major insect or disease agents were found. Since there had been several years of drought and winter injuries, these climatic conditions were cited as causing the damage. By 1969, most of the mortality had ended, and the total affected area was estimated to be about 30,000 acres (Hadfield 1969a).

1910.--A spruce budworm outbreak was reported in northern New Hampshire, but records do not indicate extensive tree kill (Avery 1976).

1890-1900.--A spruce beetle outbreak that occurred in Maine apparently extended into northern New Hampshire, killing the larger red spruce (Hopkins 1901).

1840.--A reference is made to extensive spruce mortality in the hills near Newport in Sullivan County. The spruce beetle was suspected (Hopkins 1901).

New York

1984.--The decline of spruce and balsam fir in the Adirondacks has been increasing since 1960 (USDA Forest Service 1985). Several factors appear to be involved, including overmaturity, exposed sites, winter damage, root disease, and, in some areas, the spruce beetle.

1983.--Spruce decline in higher elevations was reported to cover 37,320 acres (USDA Forest Service 1984). In addition, the spruce beetle caused tree mortality on 53,775 acres.

1982.--Declining spruce and fir on Whiteface Mountain were studied by Johnson and Siccama (1983). They indicated that spruce decline and mortality has increased rapidly over the past 20 years. Although no firm cause was determined, drought and acid deposition were suspected.

1962-80.--Scott and others (in press) reported large reductions in basal area of red spruce over a 16- to 18-year period in several stands on Whiteface Mountain in the Adirondacks. Reductions were larger at higher elevations (> 3,000 feet) than at lower elevations. There also was some reduction in basal area of balsam fir. Part of the reduction in both species was attributed to windthrow.

1970's.--Bands of balsam fir mortality from the Whiteface Mountain area were reported by Sprugel (1976).

1960's.--State reports indicate 4 years of severe winter injury to spruce in the Adirondacks following the winters of 1959, 1963, 1964, and 1967 (Miller and others 1960, 1964, 1968).

1950.--A windstorm caused blowdown of 25 percent of the standing trees on 425,000 acres in the Adirondacks. Blowdown was less extensive on about another 425,000 acres (New York State Conservation Department 1950).

1948-49.--The spruce beetle caused extensive mortality of spruce in the Adirondacks (New York State Conservation Department 1949, 1950).

1947-48.--Mortality of spruce and balsam fir occurred in the Adirondacks (Curry and Church 1952). Cold winter, warm late fall, and fall drought contributed to foliage loss from needle abscission and bud mortality. Growth reduction, branch mortality, and tree mortality were reported.

1937-38.--Widespread tree mortality in the southern Adirondacks was caused by the spruce beetle (New York State Conservation Department 1938, 1939). Reportedly, 4 million board feet of timber were destroyed near Morehouseville (Herkimer Telegram 1937).

1933.--Extensive mortality of balsam fir, spruce, tamarack, and cedar was reported. No insect or disease associated with the mortality was found (New York State Conservation Department 1934).

1871-80.--Hopkins (1901) referred to reports of great destruction of spruce in St. Lawrence County. Dr. Peck described damage by bark beetles in Hamilton County around 1874 (Felt 1906). Graves (1899) reported extensive mortality in the Adirondacks: "The spruce forests of the Adirondacks have, at different periods, been attacked by what is locally known as spruce blight, the cause of which is now recognized to be a small bark beetle, Dendroctonus rufipennis Kirby."

1840-56.--Severe spruce mortality in the Adirondacks was caused by the spruce beetle (Graves 1899).

1844-59.--Hopkins (1901) referred to Peck reporting that spruce were dying in Lewis and Renssalaer Counties, and that the spruce beetle was suspected.

1840-45.--Another spruce beetle outbreak was evident when Professor Peck discussed early attempts to utilize dead spruce (Hopkins 1901).

Vermont

1984.--Dead spruce and balsam fir were reported in pockets on 2,400 acres on the Green Mountain National Forest.[9] Balsam fir and spruce mortality from spruce budworm continues in the Northeast Kingdom--Caledonia, Essex, and Orleans Counties (USDA Forest Service 1983, 1985).

1983.--Browning of 1983 red spruce foliage and mortality of some buds were observed on many trees at Camel's Hump, Mount Mansfield, Mount Abraham, Texas Falls, Wolcott, and Bald Hill (Friedland and others 1984). Decline and mortality of spruce in higher elevations appeared to be more severe than in previous years (USDA Forest Service 1984). Armillaria root rot was reported killing spruce at Pinney Hollow following a thinning (Burns 1983).

1982.--Johnson and Siccama (1983) indicated that spruce stands in three sites in Vermont have declined over the last 20 years. They suggested that drought and acid precipitation might be involved.

1981.--Severe winter injury on 1980 red spruce needles was reported by Friedland and others (1984).

1979.--Studies on Camel's Hump, Jay Peak, Bolton Mountain, and Mount Abraham revealed that spruce stems have decreased by more than half during the previous 14-year period (Siccama and others 1982). A lack of reproduction in the study areas also was indicated.

1978.--The rate of mortality of balsam fir caused by the balsam woolly adelgid on the Green Mountain National Forest had stabilized, but some mortality was continuing.[7] Many dead and dying balsam fir and spruce were observed above 2,500 feet at Mount Ellen, Bromley Mountain, South Mountain, Mount Tabor, Bread Loaf Mountain, Mount Abraham, and Haystack Mountain. On the basis of earlier observations, the mortality was attributed to drought, old age, and poor site.

1974.--The balsam woolly adelgid caused scattered mortality on 20,000 acres. Damage was heavy on 3 to 5 acres of the Green Mountain National Forest (Allison 1975).

1971.--Red belt, or spruce dieback, was reported in Northfield, Pittsford, and Warren.[10]

1970.--Red spruce were reported dying at the Silver Lake Recreation Area, Green Mountain National Forest, but the cause could not be determined (Hadfield and Ford 1970). Mortality from balsam woolly adelgid was reported on 14,000 acres (USDA Forest Service 1970b).

1969.--Hadfield (1969b) reported balsam fir mortality from balsam woolly adelgid on the Green Mountain National Forest. He also reported scattered balsam fir and spruce mortality at high elevations, but ample regeneration.

1968.--Dying spruce were investigated on the Green Mountain National Forest (Hadfield 1968a). Mortality was attributed to Armillaria root rot. Most of the dead trees were suppressed.

1966.--Red spruce mortality was reported in high elevations on about 8,000 acres. The mortality was attributed to the past 3 years of drought (Vermont Department of Forests and Parks 1966). Armillaria root rot was reported on old-growth red spruce in Townshend State Forest and in a dense red spruce stand in Stockbridge (Vermont Department of Forests and Parks 1966).

1963-65.--Siccama (1974) reported high mortality in all age classes of red spruce at Camel's Hump below 2,600 feet during the 3-year period. Partly on the basis of previous studies, he suggested that drought and general warming of the climate were involved.

1961-62.--Severe winter injury was reported on red spruce (Vermont Department of Forests and Parks 1962).

1959.--Severe winter injury was reported on red spruce (Vermont Department of Forests and Parks 1960).

Early 1950's.--Mortality of spruce and balsam fir was investigated. Old large trees were dying (Mook and Eno 1956). Mortality was attributed to overmaturity of trees growing under severe site conditions on steep slopes.

1870-73.--Hopkins (1901) referred to reports of extensive spruce mortality in northern Vermont. The spruce beetle was considered as the probable cause.

1850.--Hopkins (1901) refers to a report of spruce turning red and dying on about 500 acres at Irasburg.

1831-32.--Hopkins (1901) refers to a record of spruce dying at Sherburne.

Summary

Survival of red spruce and balsam fir seems associated with site conditions, species composition, and age of the forest.

Spruce-Fir Flats

The spruce budworm has been the primary mortality factor in the spruce-fir flats at lower elevations in northern New England. About twice in a century, the spruce budworm reaches outbreak levels over large areas. During the outbreaks, much of the balsam fir and a lesser amount of red and white spruce over 50 to 80 years old are destroyed and a new forest begins.

Spruce-Fir Slopes

The pre-European forest on the slopes at lower elevations was predominantly red spruce, white pine, and hardwoods, with a mixture of balsam fir in wetter areas. The spruces grew large and old. Frequent spruce beetle outbreaks killed the larger spruces and released the smaller trees. Major disturbances such as hurricanes and conflagrations were infrequent, perhaps several hundred years apart (Heinselman 1978).

The arrival of the European settlers brought logging, clearing for agriculture, and frequent fires. Westveld (1953) discussed how poor logging practices and fire had resulted in poorly stocked spruce-fir forests. These forests only remotely resemble the original forest and often are subject to rapid deterioration. Spurr (1964) reviewed how man's activities have changed eastern forests. Cronon (1983) discussed the drastic changes in the forest during the colonial period in New England. Among the various effects of deforestation were lowering of water tables, drying up of springs and small streams, reduced water-holding capacity of soils, increased runoff, and drying of hillside pastures. Today, large spruce are found only in the remnant spruce stands in preserves, on inaccessible steep slopes, or in areas overlooked during logging.

High-Elevation Spruce and Fir

A large proportion of the remaining spruce and balsam fir type in mountainous regions is at higher elevations. Tree growth is limited by the short growing season; snow, ice, and wind; extreme fluctuations in temperature, and moisture. Logging was not feasible in these areas because of difficult access and small tree size. Here, red spruce and balsam fir grow slowly. Most other tree species cannot survive the adverse conditions; on the more exposed sites, even spruce and balsam fir barely survive. Winter damage occurs almost every year at the high-elevation exposed sites, causing loss of foliage. Some mountaintops became treeless when fire burned off the spruce and balsam fir, and the sites became inhospitable for spruce to return (Baldwin 1977). Strong winds occasionally uproot the taller trees. Balsam fir tends to be killed and regenerated in narrow bands or waves in 35 to 70 years, with the help of ice and wind. Prolonged drought occurs periodically and tree mortality continues for several years after the rainfall returns. Dead trees remain standing at high elevations because of the scarcity of wood-destroying organisms.

In describing the natural dynamics of the upper subalpine or fir zone in the White Mountains of New Hampshire, Reiners and Lang (1979)

referred to overlapping patterns of "fir waves, broken tree gaps, strips and glades" interrupted in places by the more discreet impressions left by hurricanes and avalanches. Because of similar conditions, they suggested that their findings also are applicable to the Green and Adirondack Mountains.

Thus, the spruce-fir forests at high elevations appear to be under continual climatic stress. A slightly drier season, a colder winter, or higher winds create another year of stress when many trees may be weakened and die on the most adverse sites. New trees grow for a while in their place. The addition of any new stress factor may not change this pattern, but further shorten the life of the trees.

SURVEY AREA

The survey area covers major portions of New York, Vermont, and New Hampshire (Fig. 1). Maine was not included in the survey because of the presence of large numbers of spruce budworm-killed spruce and balsam fir in most of the spruce-fir forest. The other New England states were not included in this survey because they have only small areas of spruce and balsam fir.

The boundaries of the survey regions within each state were delineated in consultation with State forestry agencies. Type maps were considered. In general, the areas where the spruce-fir type was likely to occur were included. In New York, two survey regions were selected: the Adirondack Region and Tug Hill Region. One survey region was established in each of the other two States (Fig. 1). In New Hampshire, the survey region included the White Mountains and portions of the Western Highlands. In Vermont, the survey region included the Green Mountain Range and the Central Plateau. Parts of the spruce-fir forest in northern New Hampshire and northeastern Vermont were not included in the survey because mortality estimates are available from spruce budworm impact surveys (Kucera and Taylor 1984). Estimates of mortality for Maine are based on about 400 permanent plots observed annually since 1975 (Brann and others 1981; Brann and others 1983; Schiltz and others 1983).

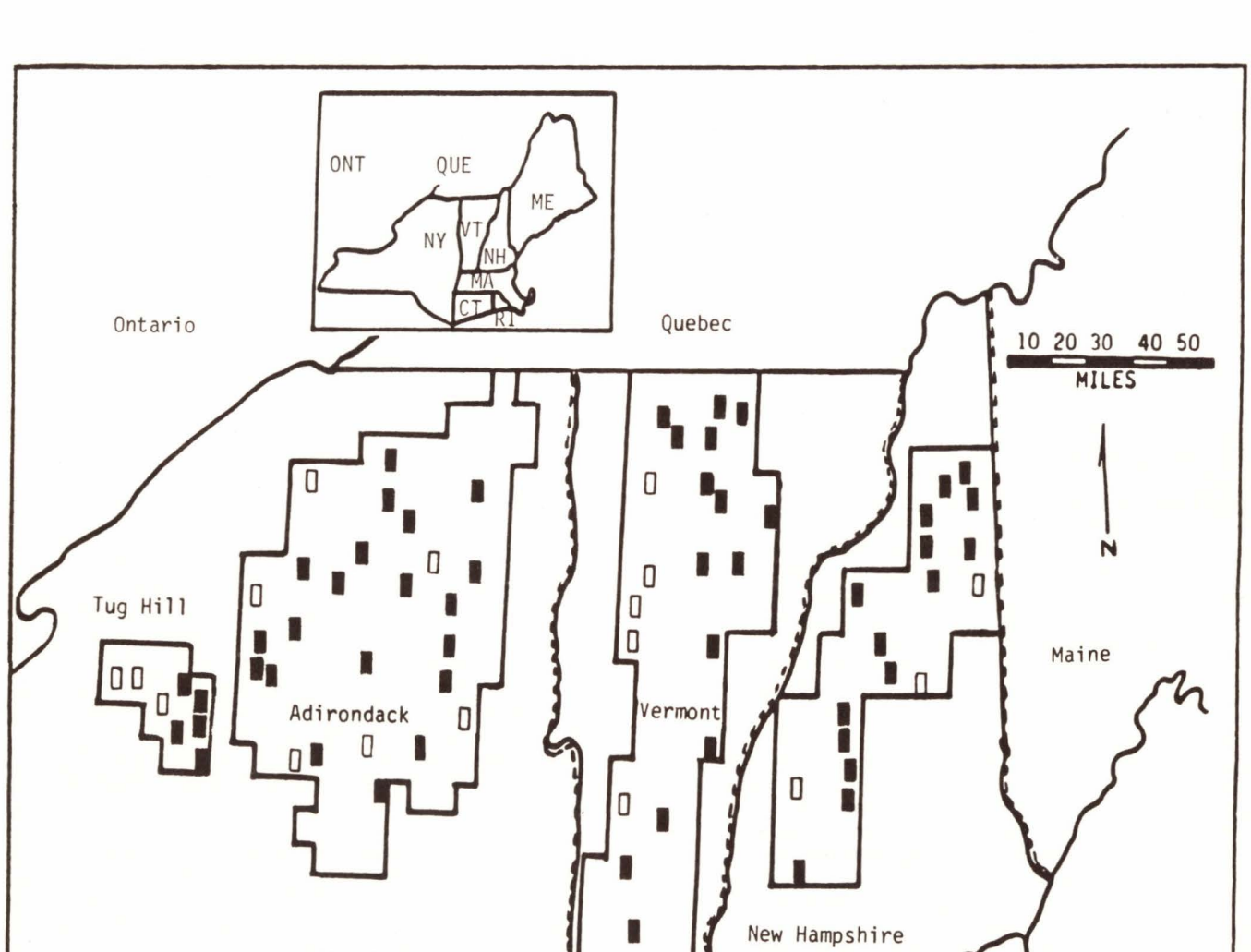

Figure 1.--Survey regions and sample blocks for Cooperative Survey of Red Spruce and Balsam Fir Decline and Mortality, 1984 (■ sample blocks photographed; □ sample blocks not photographed).

Adirondack Region

Topography

The topography of the Adirondack Region is dominated by the dome-like structure of the Adirondack physiographic province. This dome results from uplifting of Pre-Cambrian igneous and metamorphic formations over 1 billion years old (Fenneman 1938). The peaks of the Adirondacks are in random groups rather than ranges, which indicates their formation from igneous intrusive materials. The High Peaks region, with elevations reaching 5,344 feet (Mount Marcy), forms the central portion of the dome. Local relief here exceeds 2,000 feet. Surrounding the High Peaks are the Adirondacks Low Mountains, where only a few peaks reach 2,000 feet. Local relief is about 1,000 feet. On the western edge of the Adirondack Province are the Western Adirondack Hills, which are formed from Paleozoic sedimentary formations (Hunt 1974).

Glaciation and tectonic activity have influenced topography. Continental and alpine glaciation smoothed the terrain, affected drainage patterns, and produced many lakes (Fenneman 1938). Soils deposited by glaciation are described as sandy, acid, shallow, stony, and infertile (Stout 1958). Tectonic activity has influenced and continues to influence the topography. Angular drainage patterns of Adirondack streams show the influence of faulting (Lobeck 1957). Earthquakes resulting from the continued uplifting of the region occur periodically.[11]

Vegetation

There are four broad vegetation types in the Adirondacks: swamp forest, spruce flat, hardwood forest, and spruce slope (Braun 1950). The swamp forest is dominated by conifers but species composition (red spruce, black spruce, balsam fir, larch, eastern white cedar) varies among areas. Swamp forests are found at a range of altitudes. The spruce flat type occupies low areas that are not water-influence zones (bogs). Species composition usually is red spruce, yellow birch, and hemlock. The hardwood forest is dominated by deciduous species, though coniferous species are found locally in varying proportions. Species composition is primarily sugar maple and beech, with varying proportions of red spruce, yellow birch, white ash, basswood, cherry, and hemlock. The spruce slope type usually appears in areas of thin soils. This type dominates the higher elevations in the Adirondacks. From elevations of 3,200 to 4,200 feet, spruce is the dominant species. Above 4,200 feet, balsam fir is more abundant; at about 4,900 feet, timberline is reached.

Economy

The economy of the Adirondacks depends primarily on recreation and timber-based industries. Eighty-five percent of the 5.9 million acres in the Adirondacks is forested (only 4.6 million acres were included in this survey). More than 40 percent of the forest land in the Adirondacks is publicly owned, classified as state Forest Preserve, and not available for harvesting (VanValkenburgh 1983). State Forest Preserve lands provide much of the setting for recreation in this region. The remaining forest land is held primarily by large landowners (timber companies and private estates) and is available for commercial harvest (Stout 1958). One-third of New York's spruce-fir acreage is considered noncommercial. About 70 percent of this noncommercial spruce-fir acreage is classed as productive-reserved: it can produce a commercial timber crop but has been withdrawn from production by statute or administrative decision.

Forest History

Forests in the Adirondacks were relatively undisturbed until the late 1860's. Although lumber production declined in New York as a whole after 1860, logging in the Adirondacks expanded and was maintained at high levels until the 1890's (Meinig 1966). This intensification of logging, with its accompanying fires and degradation of the residual forest, led to the creation of the Adirondack Forest Preserve in 1894. There have been no commercial harvests on state Forest Preserves since 1894. Harvesting continued on private land. Timber on some private lands has been harvested several times in the last 125 years.

Tug Hill Region

Topography

The topography of the Tug Hill Region is flat to gently rolling. The survey region encompasses most of the Tug Hill Upland located to the east of Lake Ontario in north-central New York. Tug Hill is recognized as a distinct landform region of New York, separated from the Adirondack Mountains to the east and the Appalachian Uplands and Erie-Ontario Lowlands to the south and west (Miller 1924). Geologically, Tug Hill is considered an outlier of the Appalachian Plateau Province (Cressey 1966).

Tug Hill is composed of Paleozoic sedimentary formations capped by a resistant sandstone formation that has limited erosion (New York State Museum and Science Service 1966). Most sides of Tug Hill are gently sloping, but the eastern edge of the upland is a steep shale escarpment about 400 feet high that drops to a series of benches which end at the Black River. The total change in elevation is about 1,000 feet. Numerous deep gorges along this escarpment result from streams cutting through the shale formation. Elevation within the survey region ranges from about 500 feet near the Mohawk Valley to 2,100 feet on Gomer Hill, the highest point on the Tug Hill Upland. The Tug Hill Upland

encompasses about 1,000 square miles and about 70 square miles of the region is above 1,900 feet (Connor 1966). Glaciation, the slight westward dip of the cap rock formation, and the position of Tug Hill in relation to Lake Ontario act together to influence topography and vegetation on Tug Hill. The area was overridden by Pleistocene continental glaciers, and a thin layer of compacted glacial till in the subsoil results in poor soil drainage (Stout 1958). Soils on the higher elevations of Tug Hill are pure quartz sands or sandy loams with muck and peat in the swamps or bogs. At lower elevations, soils contain more clay and are derived from calcareous material (Hotchkiss 1932). The slight westward dip of the sandstone cap rock formation provides little gradient for streamflow, so that swamps and meandering streams are frequent.

Tug Hill is known for adverse climate due to its position in relation to Lake Ontario. Average annual precipitation (1931-55) was 51.43 inches at Highmarket; the region receives approximately 100 to 188 inches of snow annually (Johnson 1960). This is the highest average snowfall in the United States east of the Rocky Mountains. Heavy dew and fog also are frequent on Tug Hill (Hotchkiss 1932). This continuous supply of moisture has maintained swamps and bogs and has affected vegetation patterns. About 18 percent of Tug Hill can be classed as wetland (Temporary State Commission on Tug Hill 1976).

Vegetation

Vegetation on Tug Hill is intermediate between the Allegheny Plateau and the Adirondacks (Hotchkiss 1932). An area of virgin forest described by Hotchkiss was a stand of hardwoods and conifers (yellow birch, beech, sugar maple, red spruce, and hemlock) with a fairly open understory and a dense cover of herbs. In second-growth stands, hardwoods (yellow birch, red maple, sugar maple, beech, and black cherry) with occasional conifers (red spruce and balsam fir) dominate the higher ground, while the wet and boggy areas are dominated by conifers (spruce and tamarack) (Connor 1966). Tug Hill is in the Adirondack section of the Hemlock-White Pine-Northern Hardwood region, where red spruce is one of the dominant forest trees (Braun 1950). More Tug Hill plant species are in common with those on the Appalachian Plateau to the south than with those on the Adirondacks (Hotchkiss 1932). Thus, Tug Hill appears to be a transition zone where the cool, wet climate, along with poor soil drainage, allows boreal vegetation to exist alongside mesophytic vegetation.

Economy

The economy of the Tug Hill Region depends primarily on agriculture and food processing. Agriculture provides 15 percent of the jobs on Tug Hill and supports another 10 percent (Temporary State Commission on Tug Hill 1976). About 10 percent of the region's employed work in the forest and wood products industry. The region's forests contribute more than $80 million both in direct income and indirectly through the manufacture of wood products and paper.[12] However, the quality of today's Tug Hill forest limits the growth potential of the wood-using industry (Temporary State Commission on Tug Hill 1976). The present Tug Hill forest is predominantly low-quality hardwoods that resulted from past highgrading. Net timber production is low because of growth placed on cull trees (Stout 1958). Softwood stands account for less than 10 percent of the commercial forest acreage on Tug Hill (Temporary State Commission on Tug Hill 1974).

Recreation is becoming increasingly important in the Tug Hill Region. Twenty to forty percent of the users of state parks now come from outside the northern or central New York area (Temporary State Commission on Tug Hill 1976). Tug Hill is the source of 11 river systems that provide both cold and warm freshwater fisheries. Use of the area for winter sports is increasing as snowmobiling and cross-country skiing facilities expand. Hunting continues to be an important recreational pursuit in the area.

Forest History

Prior to the Revolutionary War, Tug Hill was unpopulated. Both Indians and European colonists rejected Tug Hill for settlement (Rayback 1966). About 1796, settlement began, and small farming and lumbering started. By 1870, Tug Hill was the center of New York's logging industry, and the region's population reached 80,000 (Temporary State Commission on Tug Hill 1976). Highgrading and selective cutting of spruce and fir for pulpwood continued through the 1940's and resulted in the present Tug Hill forest--poorly stocked, of low quality, and less than 10 percent in softwoods (Temporary Commission on Tug Hill 1974).

Vermont Region

Topography

The major topographical features in the Vermont Region are the Green Mountains. Unlike the Adirondacks or White Mountains, the Green Mountains are formed in a linear ridge system which runs north and south through the State. Narrow ridges are separated by wide, well-drained valleys. The highest peaks of the range are found in the north, where there are five peaks over 3,600 feet, the tallest being Mount Mansfield (4,451 feet). The eastern portion of the survey area is located on the Central Plateau of Vermont. Elevation on this plateau ranges from 1,200 to 2,000 feet. This plateau has broad, flattened ridgetops and narrow, deep valleys (Latimer and others 1930). Continental glaciation influenced present day

topography. The northwest to southeast movement created much steeper upper slopes on the east side of the Green Mountains than on the west (Siccama 1974). Glacial drift deposited by the last glaciation includes various sedimentary materials that do not appear in either the Adirondacks or White Mountains.

Vegetation

The spruce-fir and maple-beech-birch forest types dominate the Vermont Region (Kingsley 1977). Swamp spruce, spruce flat, mixed spruce-hardwoods, spruce slope, and old-field spruce subtypes are recognized. The old-field spruce type is found on abandoned pasture or cultivated lands. Pure stands of white or red spruce are found on such sites. Differential grazing of hardwoods and balsam fir by livestock often is cited as the reason for this condition (Murphy 1917). In the survey region, spruce-fir types are found primarily in northern Vermont, on north-facing and upper slopes in the Green Mountains, and in bogs, swamps, and other wet depressions.

Economy

Vermont's forests make valuable contributions to the State's economy in a variety of ways. The value of timber delivered (stumpage + harvesting costs + transportation costs) was estimated at $72.8 million in 1980 (Gove 1982). Combined value added by forest products manufacturers was $221.1 million, or 16 percent of all value added by manufacturing in 1980.

About 76 percent of Vermont is forested and 98 percent of the forest land (4.4 million acres) is classed as commercial forest land. About 18 percent of the commercial forest land is spruce-fir. Although spruce-fir makes up only a small proportion of the commercial forest land, it is valued highly since it provides much needed cover for Vermont's deer herd. It has been estimated that each acre of spruce-fir deer yard is worth $266 of value added to the economy (USDA Forest Service 1983).

Forest History

Growth and development in Vermont forests can be divided into five periods (O'Dell 1983). The presettlement forest was relatively undisturbed. With the arrival of colonists, logging and agricultural land clearing began. By the 1830's, the proportion of land cleared for agriculture reached a maximum. As the population and economy of Vermont changed in the 1840's, much of the agricultural land returned to forest. The area of this second-growth forest expanded until the 1880's when the need for paper introduced another period of harvesting. This was accompanied by severe railroad fires. Fire prevention and multiple use of forest resources were initiated in the early 1900's.

New Hampshire Region

Topography

The topography of the New Hampshire Region is quite varied. The region includes Mount Washington (6,288 feet), the highest peak in the Northeast, and lowlands not more than 1,000 feet in elevation. Present landforms and soils resulted from mountain building and erosion processes over millions of years. The last ice age modified the topographic features of the area and left rocky, sandy soils. Sixteen landform regions were developed by glaciation in New Hampshire (Chapman 1976); six of these landform regions are represented in the survey region.

The northern portion of the survey region includes parts of the Upper Androscoggin Lowlands and the Northern Highlands landform regions. Elevations range from 400 feet in the former region to slightly more than 3,000 feet in the latter region. The Upper Androscoggin Lowlands are a narrow basin filled with sands and gravels deposited by glacial meltwater.[13] The Northern Highlands are low mountains flanked by low hills that trend northeast-southwest. This is the most rugged section of New Hampshire outside of the White Mountains (Chapman 1976).

The central portion of the New Hampshire Region includes portions of the Whitefield Lowlands, Northern White Mountains, and Southern White Mountains landform regions. Elevations range from about 1,000 feet in the Whitefield Lowlands to more than 6,000 feet in the Northern White Mountains. The Whitefield Lowlands are an extension of the Connecticut Valley Lowlands, a preglacial valley (Chapman 1976). The floor of the Lowlands is gently rolling, sandy, and underlain with clay (Chapman 1976). The Northern and Southern White Mountains developed on plutonic and volcanic rocks which have resisted several million years of erosion.[13] The Northern section is recognized because of higher peaks (4,800 to 6,288 feet), features caused by alpine glaciation, larger local relief (2,000 to 4,000 feet), and the predominance of high-grade metamorphic rock formations. Valleys usually are narrow and filled with coarse glacial debris. Larger river valleys are broad and filled with stratified glacial outwash. The Southern White Mountain landform region is underlain primarily by granite. Peaks range from 2,500 to 4,000 feet, local relief is 1,500 to 2,500 feet, and alpine glaciation features are absent. Mountain peaks are more rounded, ponds and lakes are found, and flat valleys are more common. Much of the southern portion of the New Hampshire Region is within the Western Highlands landform region. In the east, the Western Highlands are high hills while the western and northern portions are described as low mountains.[13] Elevations range from 300 feet to more than 3,000 feet (Mount Monadnock: 3,165). The region is known for isolated mountains rising above the general upland surface; where this

occurs, local relief can exceed 1,000 feet. Differences in elevation between the Western Highlands and lowlands to the east and west have caused this highland to be deeply dissected by streams and channels, giving it a generally rugged appearance.

Vegetation

Glaciation resulted in four general land and vegetation types in the survey region. These four general associations are: alpine areas with shallow stony soils and alpine vegetation; upper mountain slopes with sandy or loamy soils covered with forests of red spruce, balsam fir, and hemlock; lower mountain slopes with numerous streams and well-drained soils supporting mixed forests of northern hardwoods and conifers; and valley areas with larger streams and sandy soils that support pine or spruce-fir forests, depending on the degree of soil drainage.

The New Hampshire Region is placed within the Hemlock-White Pine-Northern Hardwood region, and includes red spruce as a dominant species (Braun 1950). There are five forest types within the survey region (Kingsley 1976), but we are most concerned with the spruce-fir type. The occurrence of the spruce-fir type is governed by elevation, latitude, mineralogy of soil parent material, and landform (Leak 1982). In general, below 1,800 feet, spruce and fir are found where drainage is poor. Above 1,800 to 3,500 feet, red spruce dominates a forest composed of yellow birch, paper birch, and balsam fir. From 3,500 to about 4,200 feet, balsam fir is more frequent, red spruce decreases in abundance, and tree size decreases. Timberline is reached between 4,500 and 5,200 feet, depending on aspect (Braun 1950; Leak and Graber 1974). In New Hampshire, as in the Adirondacks, spruce swamp, spruce flat, mixed spruce-hardwood, spruce slope, and old-field spruce are subdivisions of the spruce-fir type (Braun 1950).

Economy

The economy of the New Hampshire survey region is based primarily on recreation. For the State as a whole, recreation contributed about 10 percent of the gross state product in 1978. Forest-based industries contributed less than 5 percent of the gross state product the same year (New Hampshire Department of Resources and Economic Development 1980). New Hampshire is the second most forested State in the Northeast, with approximately 86 percent of the land area in forest (4,985,000 acres) (New Hampshire Department of Resources and Economic Development 1980). Fourteen percent (697,700 acres) is classified as spruce-fir type. About 91 percent (635,900 acres) of the spruce-fir type is classed as commercial forest (capable of producing more than 20 cubic feet per acre per year). The remaining 61,800 acres are classed as noncommercial. About 20 percent of this noncommercial forest is productive reserve, which includes productive forest land withdrawn from timber utilization by statute (wilderness areas), administrative designation, or use as Christmas tree plantations (Kingsley 1976).

The New Hampshire Region does not include much of the spruce-fir type north of Milan because spruce and fir in this area has been affected by spruce budworm (about 106,000 acres) (Avery 1976). Because the survey area includes the White Mountains and excludes spruce-fir type stands north of Milan, it is possible that more than 9 percent of the spruce-fir type in the survey region can be classed as noncommercial. This would include both high-elevation areas not capable of producing 20 cubic feet per acre per year, and wilderness areas, research natural areas, and scenic areas designated on the White Mountain National Forest.

Forest History

Forests in New Hampshire were relatively undisturbed after the last ice age until European colonists arrived in the early 1600's. Before this time, natural phenomena (hurricanes, fires, insect outbreaks), and fires set by Indians were the only events affecting New Hampshire forests. Since colonization in the 1600's, forests have played an important part in the economy of New Hampshire (Belknap 1831). Because of land clearing for agriculture and commercial timber harvesting, forest land declined to a low of 2.8 million acres, or 48 percent of the State's land area, by 1870 (Kingsley 1976). Poor harvesting practices in the late 1800's, and severe fires which accompanied railroad logging at that time, caused much public concern about the future of New Hampshire's forests (Natti 1982).

Public outcry over the condition of the forests of the White Mountains, already a highly used recreation area, led to the passage of the Weeks Act in 1911. This Act authorized the purchase of eastern forest lands by the Federal Government. Land purchased in New Hampshire under the Weeks Act later became the White Mountain National Forest. Because of westward expansion of agriculture, farming became less profitable in New Hampshire, and farm abandonment increased after 1870. Forests reclaimed the land, and this trend continued until 1960 when about 5.1 million acres were forested.

METHODS

Sample Blocks

Each sample block was an 8,000-acre rectangle. Topographic 7.5-minute quadrangles or their equivalent were chosen at random (Fig. 1). One-quarter of each of these quadrangles was selected at random for placement of the sample block. Each sample block was examined from the air to determine if at least 100 acres of spruce-fir type were present. If not, another block was chosen at random and examined until the predetermined number of blocks with sufficient type were selected for aerial photography. The numbers of sample blocks selected and photographed in each region were:

Region	Blocks selected	Blocks photographed
Adirondack	26	20
Tug Hill	8	5
New Hampshire	18	15
Vermont	20	15

Blocks with insufficient spruce-fir type were considered as nontype in the analysis.

Stratification

Cover Types

Each photographed sample block was stratified by photo interpreters into five cover types and three mortality classes. The following cover-type strata were used:

1. Spruce-fir swamp: Low-lying bogs or swamps of at least 10 acres with more than 50 percent of the overstory in spruce or balsam fir.

2. Mixedwood: Areas of at least 10 acres with 25 to 50 percent of the overstory in spruce or balsam fir.

3. Spruce-fir slope: Areas of at least 10 acres with more than 50 percent of the overstory in spruce or balsam fir.

4. High-elevation balsam fir: A subclass of the spruce-fir slope where more than 90 percent of the stand is balsam fir with small crowns and an average d.b.h. of less than 5 inches.

5. Other: All other areas, including lakes, fields, other forest cover types, and alpine or tundra vegetation.

Mortality Classes

The four cover types containing spruce and fir were further stratified by the abundance of spruce and balsam fir mortality:

1. Light: Less than 10 percent of standing spruce and fir trees dead.

2. Moderate: 10 to 30 percent of standing spruce and fir trees dead.

3. Heavy: More than 30 percent of standing spruce and fir trees dead.

The assumption was that about 10 percent standing dead trees represents a normal forest condition. Competition and chronic insect and disease damage cause 1 to 3 percent annual mortality. Dead trees usually remain standing and retain small branches for about 5 years. The mortality classes used in this survey do not necessarily denote increasing levels of current mortality or the extent of abnormal conditions.

Samples

Photo Plots

In each of the mixedwood and spruce-fir slope mortality classes, a fixed number of photo plots were selected at random and marked on the aerial photographs (Table 1). Each photo plot was a square marked on the photo estimated to represent 2.5 acres on the ground.

The sampling intensity was 10 or more acres per plot. The number of photo plots in the Tug Hill and Vermont Regions were reduced because of insufficient acreage in the moderate and heavy mortality classes. In the Tug Hill Region, 50 photo plots had been planned for each of the two higher mortality classes. In Vermont, 150 photo plots had been planned.

Ground Plots

The ground plot is a photo plot that was selected at random for ground data gathering (Table 2). All of the photo plots in the light-mortality class were examined on the ground. A 10-percent sample of photo plots was chosen in the moderate and heavy classes for ground examination. In Tug Hill and Vermont, a higher proportion of photo plots was examined on the ground. In New Hampshire, a smaller proportion of photo plots was examined because of hazardous field conditions.

Variable-Radius Plots

In each 2.5-acre ground plot, five variable-radius plots (10 BAF) were located systematically as follows: one in the center and the other four about 2 chains away, one in each quadrant.

Table 1.--Number of photo plots, by region, cover type, and mortality class

Region	Mixedwood			Spruce-fir slope			Total
	Light mortality	Moderate mortality	Heavy mortality	Light mortality	Moderate mortality	Heavy mortality	
Adirondack	10	150	150	10	150	150	620
Tug Hill	5	32	2	5	0	0	44
New Hampshire	10	150	150	10	150	150	620
Vermont	10	82	19	10	83	60	264

Table 2.--Number of photo plots examined on the ground, by region, cover type, and mortality class

Region	Mixedwood			Spruce-fir slope			Total
	Light mortality	Moderate mortality	Heavy mortality	Light mortality	Moderate mortality	Heavy mortality	
Adirondack	10	15	11	10	15	16	77
Tug Hill	5	5	2	5	0	0	17
New Hampshire	10	8	13	10	14	9	64
Vermont	10	15	13	10	15	15	78

Regeneration Plots

At each variable-radius plot, 5 milacre plots (total of 25 milacre plots per ground plot) were established to determine the presence of regeneration. One milacre plot was located at the center and the other four 20 feet away, in each cardinal direction.

Photo Data Acquisition

Aerial Photography

Complete photo coverage was obtained of each sample block. The aerial photo mission was flown between July 14 and August 27, 1984, with a USDA Forest Service Beechcraft Queen Air aircraft equipped with a Zeiss RMK 21/23 9-inch format camera with an 8-1/4-inch focal length lens.[14] All sample blocks and flight lines were marked on USGS 7.5-, 7.5x15-, or 15-minute topographic maps to aid in aerial navigation. Sample blocks were photographed with a forward overlap of 70 percent and a sidelap of 20 percent at a scale of about 1:8,000. Kodak Aerochrome Color Infrared (CIR) film (Type 2443) was used in combination with Wratten 12 (minus blue) and antivignetting filters. CIR film was chosen to penetrate haze, separate conifers and hardwoods, and enhance conifer mortality and foliage loss. Each block was photographed using four flight lines. Approximately 56 photos were taken for each block. More than 3,000 photos were taken during the mission.

Photo Interpretation

Complete stereo coverage in the form of 9 x 9 inch CIR film positives (transparencies) was provided to photo interpreters at the Nationwide Forestry Applications Program, Houston, Texas, and at the Durham (New Hampshire) Field Office. Photo interpretation guidelines were developed for the project and provided to the interpreters (Ciesla 1984). All photos were indexed, and the principal point of every other photo frame was plotted on a 7.5-minute topographic sheet. Where 7.5-minute topographic map coverage was not available for sample blocks, 7.5-minute sections of 15-mnute topographic sheets were enlarged photographically to a scale of about 1:24,000. These enlargements were used in plotting photo locations and to facilitate further steps in the photo interpretation process. In the final step of the annotation process, the effective area of each photo frame and photo scale were determined. After annotation, photo interpreters, using Old Delft scanning stereoscopes, stratified the area within each sample block. As photo frames were examined, photo interpreters drew polygons around cover types and mortality classes directly on the CIR transparencies. Every other photo was stratified, since stereo photos overlap.

Map Transfer and Area Determination

After all photo frames within a sample block were stratified by cover type and mortality class, polygons drawn on the photo frames were

transferred to 1:24,000-scale sample block maps with a zoom transfer scope. After transfer to the 1:24,000-scale maps, polygon areas were measured with a Bausch and Lomb Resource Measurement System. The acreage in each stratum was determined in this way for each sample block.

Photo Plot Selection and Tree Counts

After all sample blocks in a region were stratified and strata acreages determined, the photo plots were allocated randomly within the mixedwood and the spruce-fir cover types. Photo plots were not established in the spruce-fir swamp and high-elevation balsam fir types. Photo interpreters used a stereoscope to count all standing dead spruce and fir trees in each photo plot. Photo interpreters did not distinguish between spruce and fir. Dead trees were defined as trees with foliage missing but most of the fine lateral branches present, or trees with all foliage red to brown (yellow on CIR film). Snags (dead trees with only a few large limbs remaining) were not counted.

Ground Data Acquisition

Ground Plots

After photo interpretation was completed, photo plots were selected at random for ground examination. Using stereoscopes, field viewers, compasses, clinometers, and 2.5-chain topographic trailer tapes or equivalents, field crews located photo plot corners as accurately as possible on the ground. Care was taken to ensure that the same trees and land area observed by photo interpreters were examined by ground crews. Boundaries of the 2.5-acre plot were traversed and marked with string. All standing dead spruce and fir (snags excluded) 5.0 inches d.b.h. and larger on the 2.5-acre plot were counted. For each dead tree, species, d.b.h., total height to nearest 10 feet, and crown class were recorded.

Variable-Radius Plots

Variable-radius plots were used to sample site and tree variables. The following site data were collected at each prism point:

1. Elevation: measured to the nearest 100 feet from topographic maps.

2. Aspect: N, NE, E, SE, S, SW, W, NW, and none.

3. Slope: flat, 0 to 10 percent; moderate, 11 to 45 percent; steep, 46 to 100 percent; very steep, >100 percent.

4. Terrain position: lowland/bottom land; hillside; ridgetop.

5. Soil depth: bedrock not exposed; bedrock exposed.

6. Soil drainage: well-drained; wet; excessively dry.

7. Crown closure: full, > 75 percent; partial, 24 to 75 percent; open, < 25 percent.

8. Age of spruce and fir (a single increment core was taken at breast height from the largest spruce or fir at each prism point). If a spruce or fir was not present, the largest tree of any species was cored. Increment cores were used for a study of radial increment trends (Hornbeck and Smith 1985).

9. Disturbance: no disturbance; recent logging (with slash), old logging (with stumps), suspected logging (roaded); natural disturbance (windthrow, fire, etc.).

At each prism point, all trees 5.0 inches d.b.h. and larger were examined. The following items were recorded for spruce and balsam fir, but only items 1 and 2 were recorded for other species:

1. Species (red spruce, black spruce, white spruce, balsam fir, white pine, hemlock, other conifers, hardwoods).

2. Diameter at breast height (2-inch classes).

3. Total height (to nearest 10 feet).

4. Number of 8-foot logs to a 4-inch top.

5. Crown class (dominant/codominant, intermediate, suppressed). The current crown position was recorded unless past crown position was different and distinguishable from the present condition.

6. Tree condition class:

   a) Healthy (less than 10 percent of crown with symptoms).

   b) Declining (10 to 50 percent of crown with symptoms).

   c) Severely declining (more than 50 percent of crown with symptoms).

   d) Recent dead (fine twigs present).

   e) Old dead (branches more than 1 inch in diameter present but fine twigs absent).

   f) Snag (all fine twigs and most branches more than 1 inch in diameter absent).

g) Windthrown, including leaners (recent with fine twigs present).

h) Windthrown (fine twigs absent).

i) Abnormal (other).

The term "declining" was meant to be descriptive of physical appearance. The use of this term does not necessarily imply an ongoing process of tree deterioration. Many of the trees classed as declining may survive indefinitely, or improve in appearance.

7. Symptoms: As many as three of the following symptoms were recorded for each tree in a decline class. The most prominent symptom was recorded first:

a) Large dead branches (> 1 inch diameter).

b) Small dead branches (< 1 inch diameter).

c) Necrotic foliage (browning).

d) Chlorotic foliage (yellowing).

e) Foliage loss (inside out).

f) Foliage loss (outside in).

g) Brooming.

h) Dead terminal (> 2 inches diameter).

i) Other.

These symptoms were chosen to best describe the physical appearance of trees. No specific cause was considered in choosing these symptoms, which can be associated with a variety of insects and diseases. The use of the word "symptom" does not imply that the tree is deteriorating or dying. A tree with one or more of these symptoms may survive indefinitely. Also, symptoms may be temporary.

8. Location of symptoms: One of the following location classes was recorded for symptoms on declining trees:

a) Upper crown.
b) Lower crown.
c) Entire crown.

9. Damage agents: If obvious, the following agents were recorded for each tree in the declining, dead, windthrown, abnormal, and other tree condition classes:

a) Human (logging damage and others).
b) Animal (porcupine damage and others).
c) Fire.
d) Other (insects and diseases). Only easily identified insect and disease agents known to cause defoliation or mortality were recorded during data collection.

Regeneration Plots

At each prism point, five milacre plots (3.7-foot radius) were established. The presence or absence of regeneration (at least one living tree 1 foot tall to 4.9 inches d.b.h.) was noted in the following categories:

1. No regeneration present.
2. Spruce present, other species may be present.
3. Spruce absent, fir present (other species may be present).
4. Stocked with commercial species other than spruce or fir.

Statistical Design

A combination of sampling procedures was used: sequential selection of random blocks; stratification of forest areas; double sampling with regression; and systematic random sampling of forest stands and plots.

Area Estimates

Acreages for the strata were determined with a sequential sampling plan to assure that a predetermined number of sample blocks in each region had at least a minimum number of acres with spruce-fir type. The sample blocks were chosen at random from a pool of blocks, without replacement of selected blocks. The sample blocks with spruce-fir type were photographed, and the strata determined by photo interpreters. The sample blocks without spruce-fir type were considered as nontype in calculations. The mean area of each stratum and its standard error were calculated for each region from sample block acreages using a correction for the sequential method.[15]

Mortality Estimates

The volume and number of dead trees in each of the three mortality classes within the spruce-fir slope and the mixedwood cover types were determined using a fixed number of photo plots in each stratum. In each photo plot, the number of dead trees was counted. A 10-percent sample of the photo plots was examined on the ground to adjust photo interpreter counts. A double sampling with regression method was used (Wear and others 1966). The mean mortality per acre of each stratum was expanded to the total acreage in the region.

Stand Descriptions

In each photo plot examined on the ground, five variable-radius (10 BAF) plots were established systematically. Mean estimates were calculated for various stand parameters. These estimates were used as samples in each region to determine strata parameters. For regeneration estimates, five milacre plots were chosen systematically at each variable-radius plot and rated for the presence of specified types of regeneration. From these, the proportion of milacre plots with regeneration was determined.

Tree Condition Evaluation

Each spruce and balsam fir tree in the variable-radius plots was rated for condition class and other tree data. Sample means per acre were used as estimates.

Computer Analysis

Field data were analyzed on the DEC 10 computer at the University of New Hampshire. The data were summarized using the 1022 and Filer data base packages, as well as the Minitab 2 statistical package. Estimates of gross cubic-foot volume were made using INVENT, a computerized inventory processor at the University of New Hampshire (Linden and Barrett 1979).

RESULTS AND DISCUSSION

Regional estimates are presented for the extent of four spruce-fir cover types and three mortality classes within each type. For the spruce-fir slope and mixedwood cover types, regional estimates are presented for number and volume of dead spruce and balsam fir, spruce and balsam fir tree condition, and regeneration stocking.

Adirondack Region

Forest Cover Area

On the basis of photo stratification of sample blocks, the spruce-fir cover types occurred on an estimated 889,200 acres (12 percent standard error of mean), or 19.1 percent of the 4.64 million acres in the Adirondack Region that were included in the survey. (The Adirondacks include an additional 1.26 million acres not included in the survey region). The percentage of the survey region in each cover type is: mixedwood, 9.8 percent; spruce-fir slope, 4.5 percent; spruce-fir swamp, 4.8 percent. Mixedwoods occupy 51.1 percent of the spruce-fir type; the spruce-fir slope amd spruce-fir swamp types occupy 23.6 and 25.2 percent, respectively. High elevation balsam fir was not found in the sample blocks. The estimate of total spruce-fir area is close to that obtained in the last forest inventory of New York by the USDA Forest Service (Considine and Frieswyk 1982). Figure 2 shows the area by cover type and mortality class for the Adirondack Region.

Mortality Area

The estimated area of each mortality class by cover type, as determined from photo stratification of sample blocks, is:

Cover type	No. of acres	Percent standard error of mean
Light-mortality class		
Mixedwood	254,600	25
Spruce-fir slope	86,500	24
Spruce-fir swamp	118,900	24
Total	460,000	16
Moderate-mortality class		
Mixedwood	149,700	29
Spruce-fir slope	65,400	27
Spruce-fir swamp	73,900	34
Total	289,000	19
Heavy-mortality class		
Mixedwood	50,500	40
Spruce-fir slope	58,100	62
Spruce-fir swamp	31,600	34
Total	140,200	30

Thus, about 16 percent of the total area of spruce-fir cover types was classified as having heavy mortality. About 28 percent of the spruce-fir slope type was classified as having heavy mortality. Only 11 percent of the mixedwood was so classified. Heavy mortality was found at all elevations. Further analysis is needed to determine whether heavy mortality was more frequent at higher or lower elevations. Areas of heavy mortality were found at all aspects, including flat areas. Again, further analysis is needed to determine differences in mortality between aspects.

Inventory of Mortality

On the basis of the photo-plot sampling method, estimated mortality of spruce and balsam fir trees in the Adirondack Region was 7.8 million trees. The total volume was 138.2 million ft^3 (Table 3). Of the total number of dead trees, 43 percent were in the large area classified as having light mortality. The average number of dead trees per acre ranged from 9.4 to 19.0 among the cover types and mortality classes (Fig. 3). The average volume of dead trees is shown in Figure 4.

Tree Condition

In the spruce-fir slope cover type, average stocking ranged from 82.2 to 95.3 spruce trees and 58.3 to 61.0 balsam fir trees per acre (Table 4). In the mixedwood cover type, average stocking ranged from 38.4 to 62.2 spruce trees and 23.9 to 40.9 balsam fir trees per acre (Table 4). Almost all of the spruces were red spruce. Estimates of basal area are shown in Table 5.

Healthy.--The highest proportion of trees was in the healthy class (Table 4). No mortality class had less than 40 percent of living trees rated as healthy. As expected from the photo stratification of mortality classes, the proportion of healthy trees decreased as the mortality classification increased.

Dead.--About 30 percent of the spruce and 34 percent of the balsam fir were dead in the mixedwood heavy-mortality class (Table 4). In the spruce-fir slope heavy-mortality class, 27 percent of the spruce and 16 percent of the balsam fir were dead (Table 4). Recent mortality of spruce was 7 percent in the mixedwood heavy-mortality class and 8 percent in the spruce-fir slope heavy-mortality class. Recent mortality of balsam fir in both classes was less than 4 percent. The distinction be-

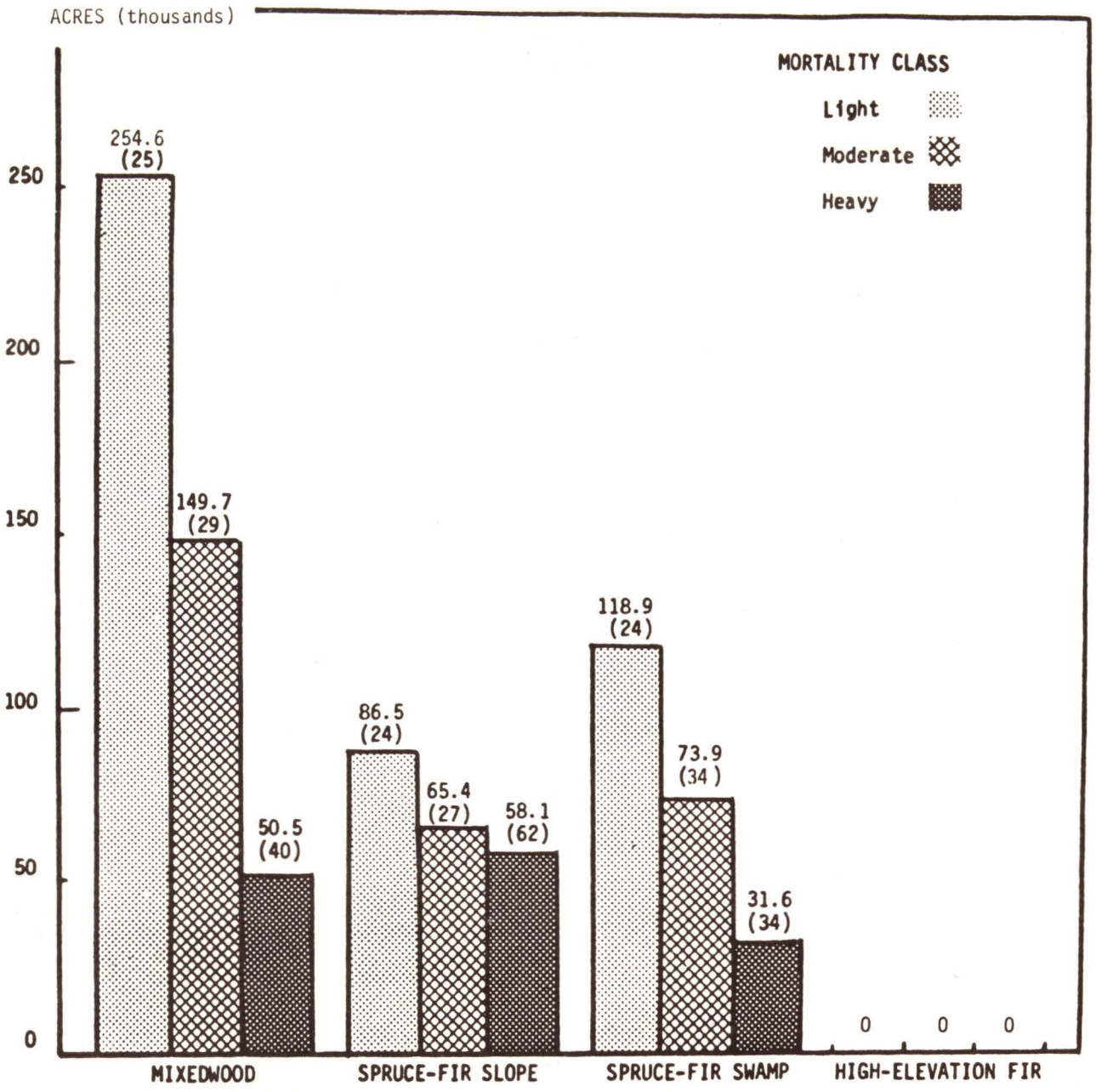

Figure 2.--Area by cover type and mortality class, Adirondack Region, 1984, based on photo interpretation of sample blocks (percent standard error in parentheses).

tween recent and old mortality is not precise because of variation in branch persistence, particularly as influenced by elevation. Our ratings were based on the expected persistence of branches at low elevations. Regardless of elevation, all dead trees with fine branches were rated as "recent dead." At lower elevations, dead trees with fine twigs present usually have died within the previous 2 years. However, at higher elevations where many of the samples were taken, the length of time that fine branches persist is not known.

Declining.--In general, the proportion of trees rated 10 to 50 percent declining was higher for spruce than balsam fir, particularly on the spruce-fir slope (Table 4). There, in the moderate-mortality class, almost one-half of the living trees were rated 10 to 50 percent declining. However, the proportion of spruce rated more than 50 percent declining is relatively low in all mortality classes and cover types. The proportion of balsam fir trees rated 10 to 50 percent declining generally is small, but higher in the spruce-fir slope than in the mixedwood type. Declining trees may include suppressed and overmature trees.

Table 3.--Number and gross volume of standing dead spruce and balsam fir trees (5.0+ inches d.b.h.), by cover type and mortality class, Adirondack Region, 1984 (based on photo-plot samples)

Cover type	Mortality class	Number of dead trees	Volume of dead trees
			Ft^3
Mixedwood	Light	2,400,000 (26)[a]	46,350,000 (26)
	Moderate	1,710,000 (30)	30,570,000 (30)
	Heavy	660,000 (40)	11,220,000 (40)
	All classes	4,770,000 (18)	88,140,000 (18)
Spruce-fir slope	Light	950,000 (27)	17,260,000 (25)
	Moderate	980,000 (27)	15,980,000 (27)
	Heavy	1,100,000 (62)	16,780,000 (62)
	All classes	3,030,000 (26)	50,020,000 (24)
Both cover types		7,800,000 (15)	138,160,000 (14)

[a] Percent standard error in parentheses.

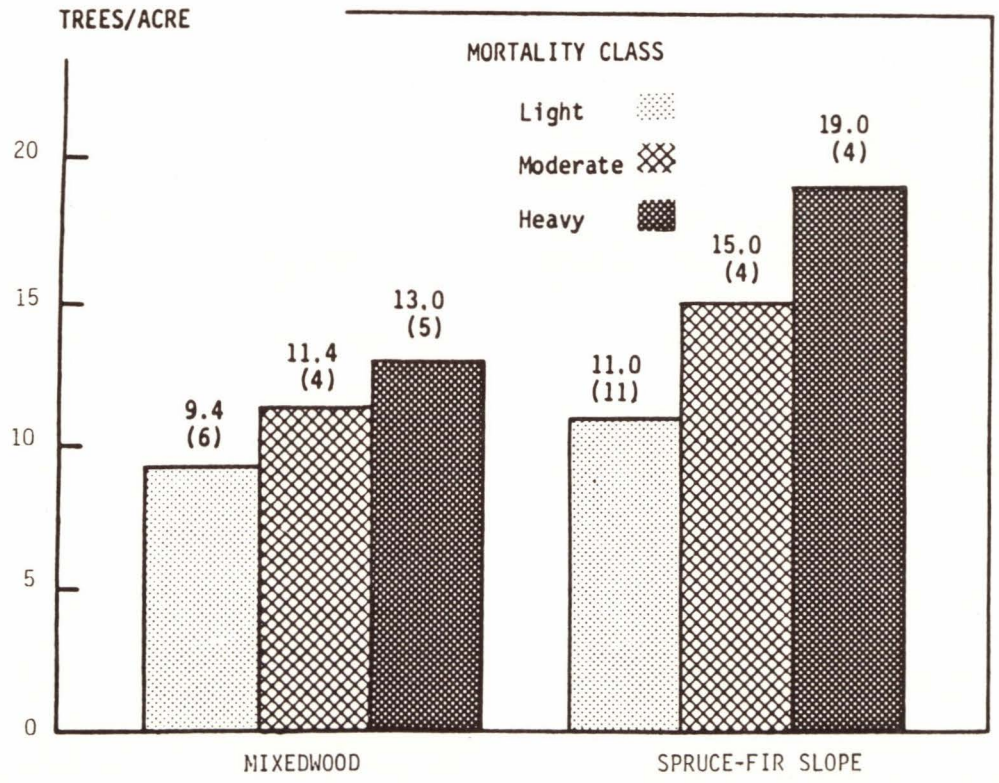

Figure 3.--Standing dead spruce and balsam fir trees 5.0+ inches d.b.h., Adirondack Region, 1984, based on photo plot samples (percent standard error in parentheses).

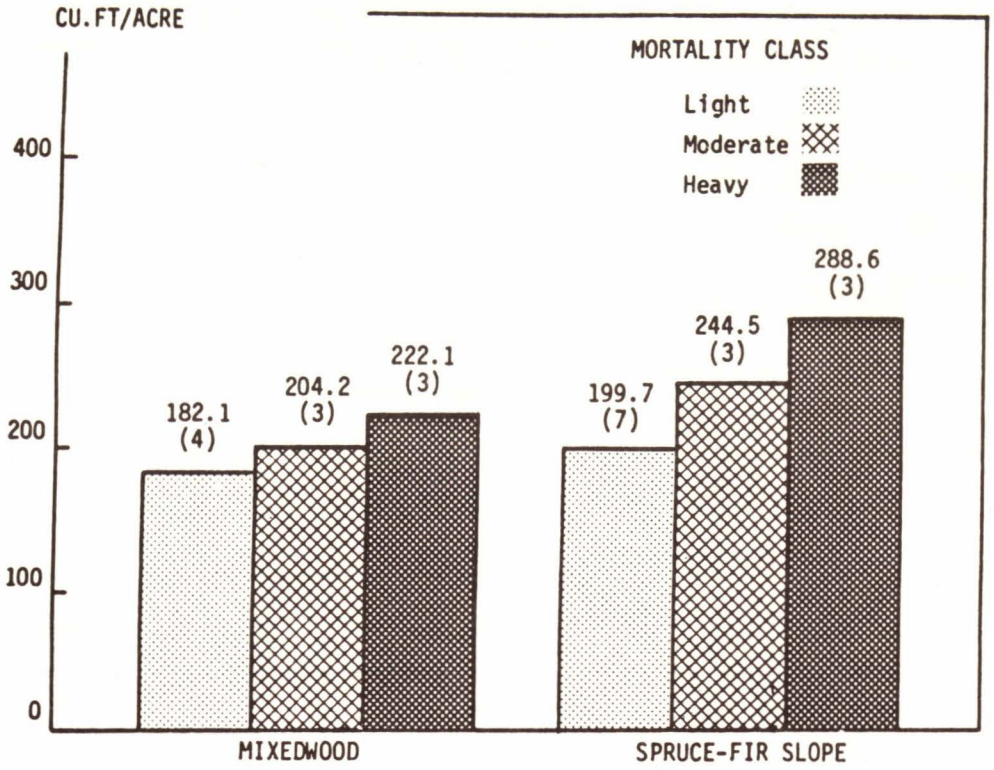

Figure 4.--Standing dead spruce and balsam fir volume for trees 5.0+ inches d.b.h., Adirondack Region, 1984, based on photo plot samples (percent standard error in parentheses).

Table 4.--Number of spruce and balsam fir trees (5.0+ inches d.b.h.) per acre, by tree condition, cover type, and mortality class, Adirondack Region, 1984 (based on variable-radius plot data)

Tree condition	Spruce-fir slope						Mixedwood					
	Light mortality		Moderate mortality		Heavy mortality		Light mortality		Moderate mortality		Heavy mortality	
	Spruce	Fir	Spruce	Fir	Spruce	Fir	Spruce	Fir	Spruce	Fir	Spruce	Fir
Live trees												
Healthy	47.8	33.1	33.0	44.6	31.8	37.8	33.5	26.1	20.9	33.5	29.4	13.5
Declining[a]												
10-50%	18.0	14.6	34.5	6.8	28.1	10.2	10.1	2.8	6.0	1.6	11.2	2.3
> 50%	7.7	0.5	4.4	0.1	9.2	0.8	4.0	2.1	4.7	0	2.9	0
All live trees	73.5	48.2	71.9	51.5	69.1	48.8	47.6	31.0	31.6	35.1	43.5	15.8
Dead trees												
Recent	1.5	2.0	10.3	2.0	7.6	2.2	5.7	1.5	0.8	2.5	4.4	0.3
Old	4.1	2.8	7.4	2.1	7.3	1.2	1.4	2.1	2.5	1.2	6.1	1.2
Snag	2.4	5.1	4.6	5.3	7.3	4.2	2.6	1.2	3.4	1.4	7.8	6.6
Windthrown	0.7	0.2	1.1	0.2	3.0	1.9	0.4	0.3	0.1	0.7	0.4	0
All dead trees	8.7	10.1	23.4	9.6	25.2	9.5	10.1	5.1	6.8	5.8	18.7	8.1
All trees	82.2	58.3	95.3	61.1	94.3	58.3	57.7	36.1	38.4	40.9	62.2	23.9

[a] Percentage classes based on proportion of crown displaying symptoms.

Table 5.--Basal area of spruce and balsam fir trees (5.0+ inches d.b.h.), by tree condition, cover type, and mortality class, Adirondack Region, 1984 (based on variable-radius plot data)

Tree condition	Spruce-fir slope						Mixedwood					
	Light mortality		Moderate mortality		Heavy mortality		Light mortality		Moderate mortality		Heavy mortality	
	Spruce	Fir	Spruce	Fir	Spruce	Fir	Spruce	Fir	Spruce	Fir	Spruce	Fir
	Ft^2/acre											
Live trees												
Healthy	19.0	10.8	15.5	13.1	15.5	10.4	15.4	8.8	13.1	10.4	16.9	3.8
Declining[a]												
10-50%	6.2	4.6	17.0	2.0	15.4	3.8	5.0	1.0	4.2	0.5	7.5	0.7
> 50%	2.8	0.4	3.1	0.1	5.1	0.2	1.2	0.6	2.8	0	1.5	0
All live trees	28.0	15.8	35.6	15.2	36.0	14.4	21.6	10.4	20.1	10.9	25.9	4.5
Dead trees												
Recent	0.6	0.6	5.3	0.4	4.1	0.7	2.2	0.6	1.1	0.8	4.0	0.2
Old	1.6	1.0	2.8	0.5	4.1	0.6	0.4	0.6	1.9	0.3	5.3	0.6
Snag	1.0	1.2	2.7	1.4	6.5	2.0	1.6	0.6	1.9	0.8	6.5	2.2
Windthrown	0.4	0.2	0.3	0.1	2.6	0.9	0.2	0.2	0.1	0.3	0.6	0
All dead trees	3.6	3.0	11.1	2.4	17.3	4.2	4.4	2.0	5.0	2.2	16.4	3.0
All trees	31.6	18.8	46.7	17.6	53.3	18.6	26.0	12.4	25.1	13.1	42.3	7.5

[a] Percentage classes based on proportion of crown displaying symptoms.

The symptoms most frequently recorded to describe declining trees were small dead branches, loss of foliage from the outside in, chlorotic foliage and necrotic foliage. These symptoms may be associated with any of a large number of causes. For example, trees injured by drought typically die from the top down and the outside in (Boyce 1961). Branch dieback also may be associated with root diseases such as shoestring root rot caused by the fungus Armillaria mellea. Branch dieback also may result from defoliator feeding. The foliar symptoms observed could be caused by any of a number of agents. In each situation, further examination of individual trees is required.

Windthrow.--Windthrown trees were not abundant in the Adirondack Region (Table 4). The highest number of windthrown trees was in the spruce-fir slope heavy-mortality class.

Regeneration

Spruce regeneration was present on an average of 28.4 percent of the milacre plots in the spruce-fir slope light-mortality class, and on 74.9 percent of the milacre plots in the mixedwood heavy-mortality class (Table 6). For all mortality classes of both cover types, more than 50 percent of the milacre plots were stocked to spruce, balsam fir, or both. Less than 25 percent of the milacre plots were rated nonstocked with commercial tree species. The percentage of plots stocked with spruce generally increased as mortality increased.

Regional Summary

In the Adirondack Region, spruce-fir cover types are present on 19.1 percent of the area, or about 889,200 acres. Of the spruce-fir area, 51.1 percent (454,800 acres) is mixedwood; 23.6 percent (210,000 acres) is spruce-fir slope; and 25.2 percent (224,500 acres) is spruce-fir swamp. Heavy mortality was found on an estimated 11 percent of the mixedwood and 28 percent of the spruce-fir slope type. Areas of heavy mortality were found at all elevations and aspects.

A total of 7.8 million trees with a volume of 138.2 million ft^3 are dead. Of these dead trees, 43 percent were in the large area of light-mortality in the mixedwood and spruce-fir slope types. The highest number of dead trees per acre (19.0) and the highest volume of dead trees per acre (288.6 ft^3) were in the heavy-mortality class of the spruce-fir slope. Much of the mortality in all mortality classes may be caused by suppression, chronic insect and disease problems, and old age.

The proportion of live spruce rated healthy ranged from 46 to 70 percent. The proportion of balsam fir rated healthy ranged from 52 to 95 percent. The lowest percentage of spruce rated healthy was in the spruce-fir slope moderate-mortality class and spruce-fir slope heavy-mortality class.

Table 6.--Regeneration stocking (at least 12 inches tall but less than 5.0 inches d.b.h.), by stocking class, cover type, and mortality class, Adirondack Region, 1984 (based on milacre plots)

Stocking class	Spruce-fir slope			Mixedwood		
	Light mortality	Moderate mortality	Heavy mortality	Light mortality	Moderate mortality	Heavy mortality
	Percent					
Spruce present	28.4	48.5	66.0	43.6	42.9	74.9
Fir present/spruce absent	32.8	14.4	12.0	8.8	11.2	5.5
Other commercial species only	17.2	12.8	8.5	26.8	22.9	14.2
Total stocked	78.4	75.7	86.5	79.2	77.0	94.6
Nonstocked	21.6	24.3	13.5	20.8	23.0	5.4

In the light-mortality class, annual mortality is estimated at 1 to 5 percent, assuming that the "recent dead" class includes only 2 years of mortality. This compares with our calculations based on past statewide forest survey estimates (Armstrong and Bjorkbom 1956; Considine and Frieswyk 1982; Ferguson and Mayer 1970) that show that annual mortality of growing stock was about 1.3 percent in 1953, 1.8 percent in 1969, and 1.5 percent in 1980. For sawtimber-size spruce and balsam fir, annual mortality was about 2.3 percent in 1953, 1 percent in 1969, and 1.4 percent in 1980. However, direct comparison with forest survey data in the Adirondacks may not be valid since our survey, unlike forest inventory surveys, included a large proportion of the noncommercial high-elevation forest.

Spruce regeneration was most abundant where the density of overstory was reduced by mortality. In the heavy mortality areas, about 70 percent of the milacre plots were stocked with spruce, and nearly 80 percent of the milacre plots had spruce, fir, or both.

Examination of aerial photos showed that mortality in the spruce-fir swamp cover type is primarily on the perimeter of these wet areas. Such a pattern usually is the result of fluctuations in the water table, either from drought or from flooding by beaver dams.

Tug Hill Region

Forest Cover Area

On the basis of photo stratification of sample blocks, the spruce-fir cover types occur on an estimated 23,100 acres (26 percent standard error), or about 4.8 percent of the 484,000 acres in the Tug Hill Region. The percentage of the survey region in each cover type is: mixedwood, 2.8 percent; spruce-fir slope, 1.9 percent; spruce-fir swamp, 0.1 percent. Mixedwoods occupy about 57.6 percent of the spruce-fir type. The remaining area is mostly spruce-fir slope (39.4 percent) and spruce-fir swamp (3.0 percent). High-elevation balsam fir was not found in the sample blocks. Figure 5 shows the area by cover type and mortality class for the Tug Hill Region.

Mortality Area

The estimated area of each mortality class by cover type, as determined from photo stratification of sample blocks, is:

Cover type	No. of acres	Percent standard error of mean
Light-mortality class		
Mixedwood	10,900	38
Spruce-fir slope	9,100	44
Spruce-fir swamp	500	97
Total	20,500	28
Moderate-mortality class		
Mixedwood	2,200	72
Spruce-fir slope	0	0
Spruce-fir swamp	100	103
Total	2,300	70
Heavy-mortality class		
Mixedwood	200	103
Spruce-fir slope	0	0
Spruce-fir swamp	100	66
Total	300	67

The total estimated area of heavy mortality was only 300 acres, of which 100 acres were spruce-fir swamp type that was not ground checked. The other 200 acres were in the mixedwood type. About 82 percent of the mixedwood type was classified as having light mortality. All of the spruce-fir slope type was classified as having light mortality. Almost all of the spruce-fir type in Tug Hill is at about the same elevation (2,000 feet), so no elevation and mortality relationships are apparent.

Inventory of Mortality

On the basis of photo-plot sampling, the estimated mortality of spruce and balsam fir in the Tug Hill Region was 283,000 trees. The total volume was 2.48 million ft^3 (Table 7). Most of the mortality volume (88 percent) was on the large area classified as having light mortality. The average number of dead trees per acre ranged from 12.0 to 23.7 among the cover types and mortality classes (Fig. 6). The average cubic-foot volume of dead trees per acre is shown in Figure 7.

Tree Condition

In the spruce-fir slope type, average stocking was 25.4 spruce trees and 128.6 balsam fir trees per acre (Table 8). The average basal area was 14.4 and 42.8 ft^2, respectively (Table 9). In the mixedwood type, average stocking ranged from 54.6 to 64.0 spruce trees per acre and 52.6 to 120.2 balsam fir trees per acre (Table 8). In the mixedwoods, the average basal area for spruce ranged from 24.4 to 31.2 ft^2 per acre and from 17.0 to 37.2 ft^2 per acre for balsam fir (Table 9). The average basal area per tree suggests that most of the trees are small.

Healthy.--Less than 25 percent of the spruce and less than 50 percent of the balsam fir were rated as healthy (Table 8). Only 1 percent of the spruce trees was rated as healthy in the mixedwood light-mortality class.

Dead.--On the spruce-fir slope, all of which was classified as having light mortality, 18 percent of the spruce and 25 percent of the balsam fir were dead (Table 8). The dead spruce are smaller than the live spruce, with an average basal area per dead tree about one-half that of the average live tree. The dead balsam fir seem to be the same size as the live balsam fir. About 71 percent of the dead spruce and 42 percent of the dead balsam fir had died recently.

In the mixedwood type, mortality of spruce ranged from 11 to 28 percent; mortality of balsam fir ranged from 18 to 34 percent (Table 8). Comparison of basal area per tree indicates that the size of the dead trees does not differ greatly from that of the live trees. The proportion of spruce trees classified as recently dead ranged from 51 to 100 percent of all dead trees. Balsam fir trees classified as recently dead ranged from 21 to 81 percent of all dead trees. Thus, it appears that many of the dead trees died recently, probably within the last 2 years.

Declining.--A high proportion of the living trees was rated as declining (Table 8). In the spruce-fir slope, 76 percent of live spruce and 51 percent of live balsam fir were rated 10 to 50 percent declining, and less than 10 percent of both species were rated more than 50 percent declining. In the mixedwood type, 21 to 64 percent of live spruce and 23

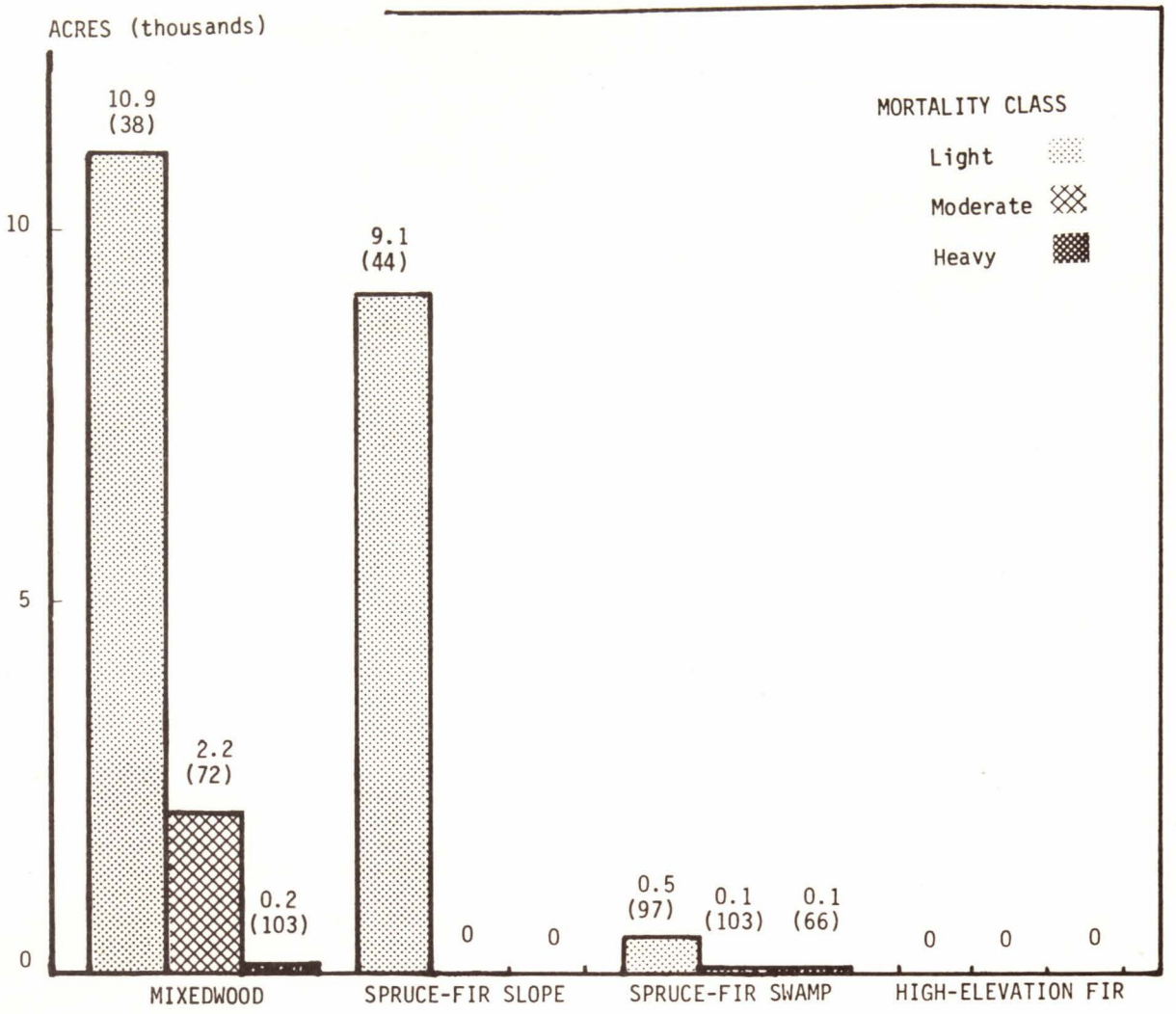

Figure 5.--Area by cover type and mortality class, Tug Hill Region, 1984, based on photo interpretation of sample blocks (percent standard error in parentheses).

to 48 percent of live balsam fir were rated 10 to 50 percent declining. In addition, 10 to 59 percent of live spruce and 12 to 19 percent of live balsam fir were rated more than 50 percent declining. Tree condition does not seem related to the mortality classification of the mixedwood type.

The symptoms most frequently recorded to describe declining trees were small dead branches (spruce and fir), chlorotic foliage (spruce and fir), loss of foliage from the inside out (fir only), and necrotic foliage (spruce and fir). These symptoms may be associated with any of a large number of causes. Loss of foliage from the inside out can be associated with suppression (Curry and Church 1952) or with needlecast diseases (Boyce 1961). Branch dieback may be associated with root diseases such as shoestring root rot caused by Armillaria mellea. Branch dieback also can result from defoliator feeding. Chlorotic and necrotic foliage can be caused by any of a number of agents. In each situation, intensive examination of individual trees is required for diagnosis.

Windthrow.--Windthrown trees were more common among balsam fir than among spruce (Table 8). For spruce, windthrow ranged from zero to 4 percent, with the highest proportion in the spruce-fir slope type. For balsam fir, windthrow ranged from zero to 14 percent, with the highest proportion in the mixedwood light-mortality class.

Table 7.--Number and gross volume of standing dead spruce and balsam fir trees (5.0+ inches d.b.h.), by cover type and mortality class, Tug Hill Region, 1984 (based on photo-plot samples)

Cover type	Mortality class	Number of dead trees		Volume of dead trees	
				Ft^3	
Mixedwood	Light	140,000	(40)[a]	1,230,000	(40)
	Moderate	30,000	(72)	280,000	(72)
	Heavy	3,000	(107)	30,000	(107)
	All classes	173,000	(33)	1,540,000	(33)
Spruce-fir slope	Light	110,000	(46)	940,000	(46)
	Moderate	0		0	
	Heavy	0		0	
	All classes	110,000	(46)	940,000	(46)
Both cover types		283,000	(28)	2,480,000	(28)

[a] Percent standard error in parentheses.

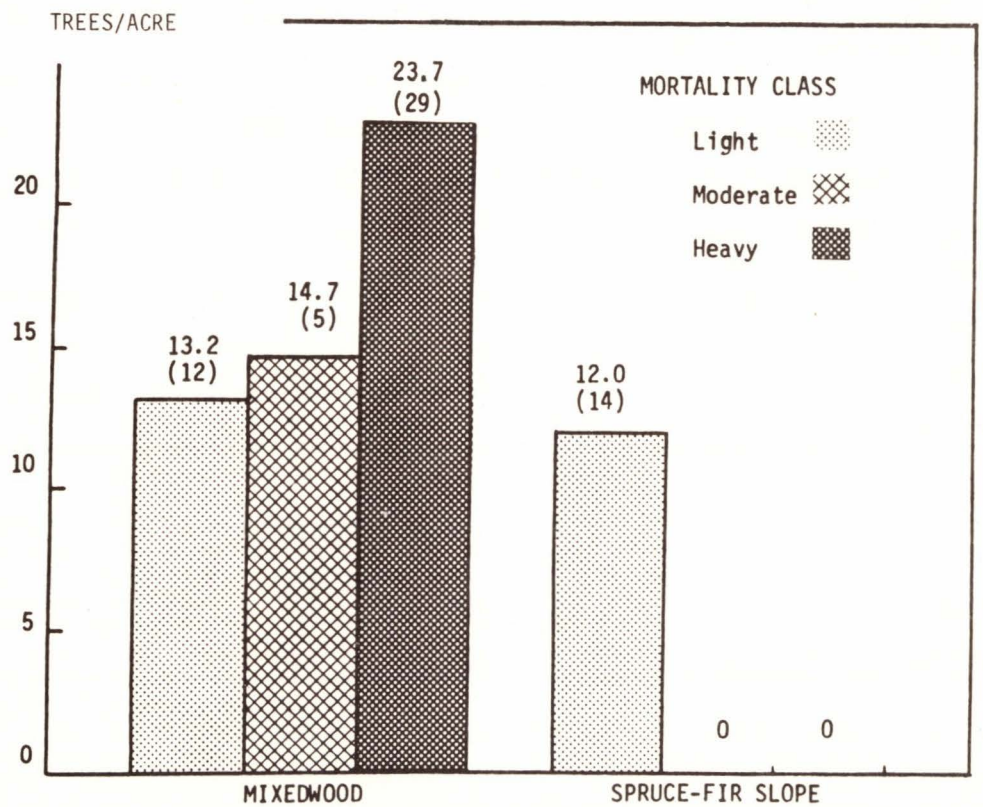

Figure 6.--Standing dead spruce and balsam fir trees 5.0+ inches d.b.h., Tug Hill Region, 1984, based on photo plot samples (percent standard error in parentheses).

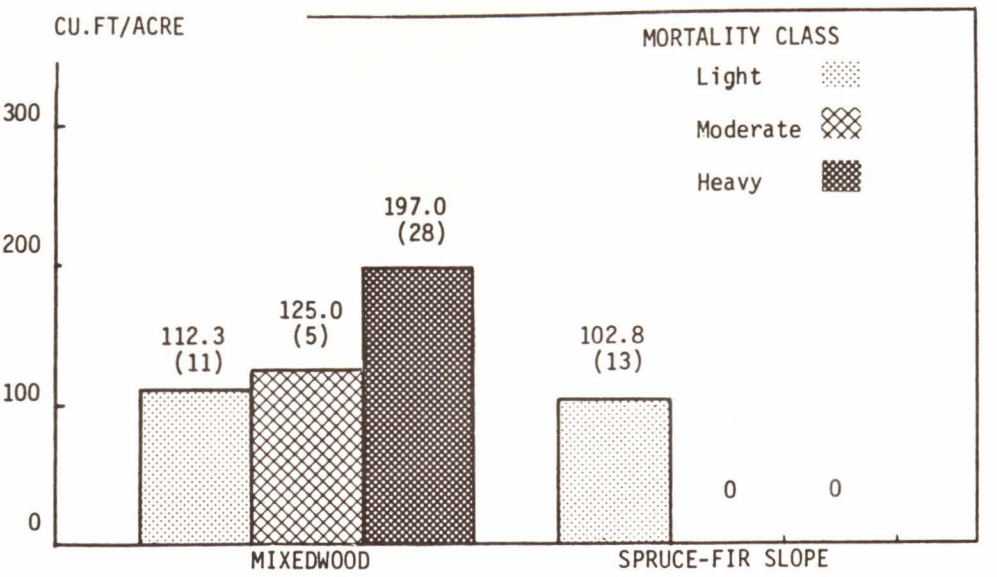

Figure 7.--Standing dead spruce and balsam fir volume for trees 5.0+ inches d.b.h., Tug Hill Region, 1984, based on photo plot samples (percent standard error in parentheses).

Table 8.--Number of spruce and balsam fir trees (5.0+ inches d.b.h.) per acre, by tree condition, cover type, and mortality class, Tug Hill Region, 1984 (based on variable-radius plot data)

Tree condition	Spruce-fir slope		Mixedwood					
	Light mortality[a]		Light mortality		Moderate mortality		Heavy mortality	
	Spruce	Fir	Spruce	Fir	Spruce	Fir	Spruce	Fir
Live trees								
Healthy	3.6	47.4	0.7	30.6	12.7	47.3	10.2	25.1
Declining[b]								
10-50%	15.8	48.9	21.9	35.7	31.0	22.2	10.8	9.8
> 50%	1.5	0.3	23.6	8.7	5.0	10.2	30.1	8.4
All live trees	20.9	96.6	46.2	75.0	48.7	79.7	51.1	43.3
Dead trees								
Recent	3.2	13.6	9.1	11.9	5.7	8.6	6.6	7.5
Old	0.2	5.5	0.5	0	0	2.9	0	1.8
Snag	0	3.0	6.4	5.1	0.2	23.1	0	0
Windthrown	1.1	9.9	1.8	14.4	0	5.9	0	0
All dead trees	4.5	32.0	17.8	31.4	5.9	40.5	6.6	9.3
All trees	25.4	128.6	64.0	106.4	54.6	120.2	57.7	52.6

[a] Moderate and heavy mortality not detected in spruce-fir slope type.

[b] Percentage classes based on proportion of crown displaying symptoms.

Table 9.--Basal area of spruce and balsam fir trees (5.0+ inches d.b.h.), by tree condition, cover type, and mortality class, Tug Hill Region, 1984 (based on variable-radius plot data)

Tree condition	Spruce-fir slope		Mixedwood					
	Light mortality[a]		Light mortality		Moderate mortality		Heavy mortality	
	Spruce	Fir	Spruce	Fir	Spruce	Fir	Spruce	Fir
	Ft^2/acre							
Live trees								
Healthy	1.2	12.0	0.4	10.8	4.4	13.2	2.0	6.0
Declining[b]								
10-50%	10.0	19.6	12.0	12.4	13.6	8.0	3.0	3.0
> 50%	1.6	0.4	11.2	2.8	3.2	3.6	18.0	4.0
All live trees	12.8	32.0	23.6	26.0	21.2	24.8	23.0	13.0
Dead trees								
Recent	0.8	3.2	4.8	3.2	2.4	2.8	3.0	3.0
Old	0.4	2.4	0.4	0	0	2.0	0	1.0
Snag	0	1.2	1.6	2.0	0.8	6.0	0	0
Windthrown	0.4	4.0	0.8	5.6	0	1.6	0	0
All dead trees	1.6	10.8	7.6	10.8	3.2	12.4	3.0	4.0
All trees	14.4	42.8	31.2	36.8	24.4	37.2	26.0	17.0

[a] Moderate and heavy mortality not detected in spruce-fir slope type.

[b] Percentage classes based on proportion of crown displaying symptoms.

Regeneration

Spruce regeneration was present on an average of 4.8 to 16.8 percent of the milacre plots (Table 10). The lowest proportion of spruce regeneration was on the spruce-fir slope, while the highest was in the mixedwood light mortality class. Regeneration of spruce, balsam fir, or both, was in 25.6 to 46.2 percent of the milacre plots, and was lowest in the spruce-fir slope light-mortality class. Regeneration of spruce, balsam fir, or both, also was low, 26.0 percent, in the mixedwood high-mortality class. The percentage of nonstocked plots ranged from 35.2 to 42.0.

Aerial Survey

The Forest Pest Management staff, USDA Forest Service, surveyed the Tug Hill Region by aircraft on November 15, 1984. The purpose was to determine if photo sampling might have missed major areas of spruce-fir type, or if large areas of tree mortality were missed. The survey confirmed that the spruce-fir type in the Tug Hill Region is small, and that tree mortality is not extensive. Since the survey occurred after hardwoods had dropped their leaves, conifer mortality in the mixedwood type could not be determined unless red foliage was present on dead conifers.

Regional Summary

In the Tug Hill Region, spruce-fir types are present on 4.8 percent of the area, or about 23,100 acres. Of the spruce-fir area, 57.6 percent (13,300 acres) is mixedwood; 39.4 percent (9,100 acres) is spruce-fir slope; and 3.0 percent (700 acres) is spruce-fir swamp. An estimated 300 acres of the spruce-fir types were classified as having heavy mortality. Of that, 200 acres were in mixedwood type, while the remainder was in spruce-fir swamp.

Most of the estimated 283,000 dead trees, (volume of 2.48 million ft^3), were in the mixedwood light-mortality class and the spruce-fir slope light-mortality class. The highest number of dead trees per acre (23.7) and highest volume of dead trees per acre (197.0 ft^3) were in the mixedwood heavy-mortality class.

The proportion of dead trees per acre ranged from 11 to 28 percent for spruce and from 18 to 34 percent for balsam fir. Most of the dead trees appear to be of small size.

Table 10.--Regeneration stocking (at least 12 inches tall but less than 5.0 inches d.b.h.), by stocking class, cover type, and mortality class, Tug Hill Region, 1984 (based on milacre plots)

Stocking class	Spruce-fir slope[a]	Mixedwood		
	Light mortality	Light mortality	Moderate mortality	Heavy mortality
	Percent			
Spruce present	4.8	16.8	15.2	8.0
Fir present/spruce absent	20.8	21.6	31.2	18.0
Other commercial species only	32.8	26.4	12.0	32.0
Total stocked	58.4	64.8	58.4	58.0
Nonstocked	41.6	35.2	41.6	42.0

[a] Moderate and heavy mortality not detected in spruce-fir slope type.

On the spruce-fir slope, 71 percent of dead spruce and 42 percent of dead balsam fir died recently. In the mixedwood, 51 to 100 percent of dead spruce and 21 to 81 percent of dead balsam fir were rated as recently dead.

Less than 25 percent of the spruce and less than 50 percent of the balsam fir were rated as healthy. A high proportion of living trees was rated in one of the two declining classes. On the spruce-fir slope, 76 percent of live spruce and 51 percent of live balsam fir were rated 10 to 50 percent declining . In the mixedwood, 21 to 64 percent of live spruce and 23 to 48 percent of live balsam fir were rated 10 to 50 percent declining. Up to 59 percent of live spruce and up to 19 percent of live balsam fir were rated more than 50 percent declining.

Windthrow in the Tug Hill Region was high among balsam fir and reached 14 percent of all trees in the mixedwood light-mortality class.

Spruce regeneration stocking averaged 16.8 percent or less of milacre plots. Up to 42 percent of the milacre plots were nonstocked.

Vermont Region

Forest Cover Area

On the basis of photo stratification of the sample blocks, the spruce-fir cover types occur on an estimated 275,600 acres (17 percent standard error), or about 8.3 percent of the nearly 3.34 million acres in the Vermont Region. The percentage of the survey region in each cover type is: mixedwood, 3.6 percent; spruce-fir slope, 4.0 percent; spruce-fir swamp, 0.7 percent. High-elevation balsam fir was not found in the sample blocks. Figure 8 shows the area by cover type and mortality class for the Vermont Region. Only about one-third of the spruce-fir in Vermont is within the survey region (Kingsley 1977). The remainder is mostly in northeastern Vermont, which was not included in the survey because of the damage from an outbreak of the spruce budworm.

Mortality Area

The estimated area of each mortality class by cover type, as determined from photo stratification of sample blocks, is:

Cover type	No. of acres	Percent standard error of mean
Light-mortality class		
Mixedwood	99,000	24
Spruce-fir slope	103,000	34
Spruce-fir swamp	9,200	76
Total	211,200	32
Moderate-mortality class		
Mixedwood	17,000	39
Spruce-fir slope	17,200	34
Spruce-fir swamp	8,000	100
Total	42,200	48
Heavy-mortality class		
Mixedwood	3,900	86
Spruce-fir slope	12,400	53
Spruce-fir swamp	5,900	74
Total	22,200	42

About 8 percent of the total area of spruce-fir cover types was classified as having heavy mortality, of which more than half was in the spruce-fir slope type. About 9 percent of the spruce-fir slope was classified as having heavy mortality. About 3 percent of the mixedwood type was classified as having heavy mortality. About 25 percent of the spruce-fir swamp was classified as having heavy mortality. Overall, more than three-quarters of the area of spruce-fir cover types was classified as having light mortality.

The heavy-mortality areas in the sample were at higher elevations, (above 2,000 feet). Preliminary analysis indicates that mortality of spruce and balsam fir tends to increase with elevation. A more thorough examination of our data, and perhaps additional data collection, will be needed to confirm this observation. There were heavy-mortality plots in all aspects, including flat areas.

In the spruce-fir slope type, 24 percent of live spruce basal area and 10 percent of dead spruce basal area was white spruce. All of the white spruce mortality was in the light- and moderate-mortality classes. There were no dead white spruce in the heavy-mortality class. In the mixedwood type, only 3 percent of live spruce and none of the dead spruce were white spruce.

Inventory of Mortality

On the basis of photo-plot sampling, estimated total mortality of spruce and balsam fir in the Vermont Region was 2.7 million trees. The total volume was 27.5 million ft^3 (Table 11). Almost 75 percent of the dead trees and dead volume was in the large area in the light-mortality classes. The highest density of dead trees and dead tree volume was in the spruce-fir slope heavy-mortality class. Here, about 60 percent higher mortality was observed than in the light-mortality class. The average number of dead trees per acre ranged from 10.0 to 16.5 among the cover types and mortality classes (Fig. 9). The average cubic-foot volume of dead trees per acre is shown in Figure 10.

Tree Condition

In the spruce-fir slope type, average stocking ranged from 69.0 to 119.0 spruce trees and 39.7 to 63.1 balsam fir trees per acre (Table 12). Of the spruce, about 76 percent were red spruce and 23 percent were white spruce. In the mixedwood type, average stocking ranged from 15.8 to 59.1 spruce trees and 9.0 to 69.6 balsam fir trees per acre (Table 12). In the mixedwoods, the spruce component was about 98 percent red spruce. The basal area of spruce ranged from 24.6 to 51.1 ft^2 per acre in the spruce-fir slope type and from 7.4 to 23.3 ft^2 per acre in the mixedwood type (Table 13).

In the spruce-fir slope type, white spruce made up 24 percent of live and 10 percent of dead spruce basal area. The proportion of white spruce to all spruce within mortality classes was: light, 45 percent of live and 20 percent of dead spruce; moderate, 36 percent of live and 21 percent of dead spruce; heavy, none live or dead. Overall, about 87 percent of white spruce were rated as healthy. In the mixedwoods, white spruce made up only 3 percent of the live spruce and none of the dead spruce basal area.

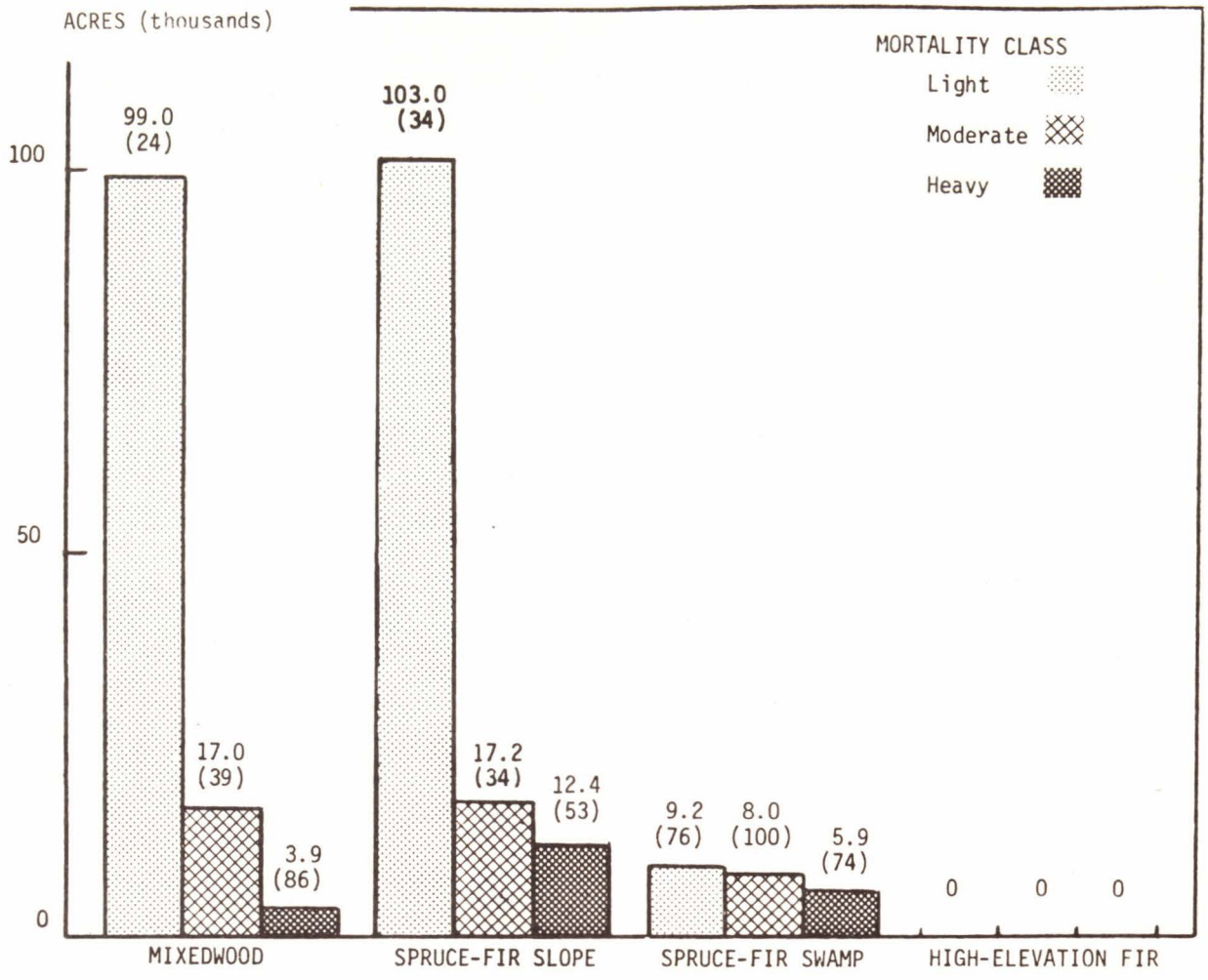

Figure 8.--Area by cover type and mortality class, Vermont Region, 1984, based on photo interpretation of sample blocks (percent standard error in parentheses).

Healthy.--A high proportion of the spruce and balsam fir were rated as healthy. Even in the heavy-mortality classes, more than 30 percent of the trees were rated as healthy.

Dead.--The largest number of dead trees was in the spruce-fir slope heavy-mortality class, where an average of 38 trees per acre were dead (Table 12). Dead balsam fir and spruce were present in equal numbers. In the mixedwood heavy-mortality class, 32 trees per acre were dead and more than 80 percent of the dead trees were balsam fir. Recent mortality of spruce was highest in the spruce-fir slope heavy-mortality class, where 38 percent of the dead spruce were rated as recently dead. Old mortality and snags combined outnumbered recently dead in all cover types and mortality classes. Less than 5 percent of the large number of dead balsam fir in the mixedwood heavy-mortality class were rated as recently dead.

The distinction between recent and old mortality is not precise, because of variation in branch persistence. Our ratings were based on the expected persistence of branches at low elevations. Regardless of elevation, all dead trees with fine branches were rated as recently dead. Dead trees with fine twigs present usually have died within the previous two years. However, at higher elevations, the length of time that fine branches persist is not known.

Declining.--The highest percentages of live trees rated as 10 to 50 percent declining were in the heavy-mortality class of the spruce-fir slope--21 percent of spruce and 25 percent of balsam fir. In the mixedwood heavy-mortality class, the percentages were 22 for spruce and 52 for balsam fir (Table 12). Trees rated more than 50 percent declining generally were much fewer in number than trees rated 10 to 50 percent declining. The highest proportion of trees rated more than 50 percent declining (18 percent) was spruce in the mixedwood heavy-

Table 11.--Number and gross volume of standing dead spruce and balsam fir trees (5.0+ inches d.b.h.), by cover type and mortality class, Vermont Region, 1984 (based on photo-plot samples)

Cover type	Mortality class	Number of dead trees	Volume of dead trees
			Ft^3
Mixedwood	Light	1,000,000 (25)[a]	10,060,000 (25)
	Moderate	180,000 (39)	1,790,000 (39)
	Heavy	60,000 (86)	620,000 (86)
	All classes	1,240,000 (21)	12,470,000 (22)
Spruce-fir slope	Light	1,030,000 (34)	10,360,000 (34)
	Moderate	260,000 (35)	2,580,000 (35)
	Heavy	210,000 (54)	2,050,000 (54)
	All classes	1,500,000 (25)	14,990,000 (26)
Both cover types		2,740,000 (17)	27,460,000 (17)

[a] Percent standard error in parentheses.

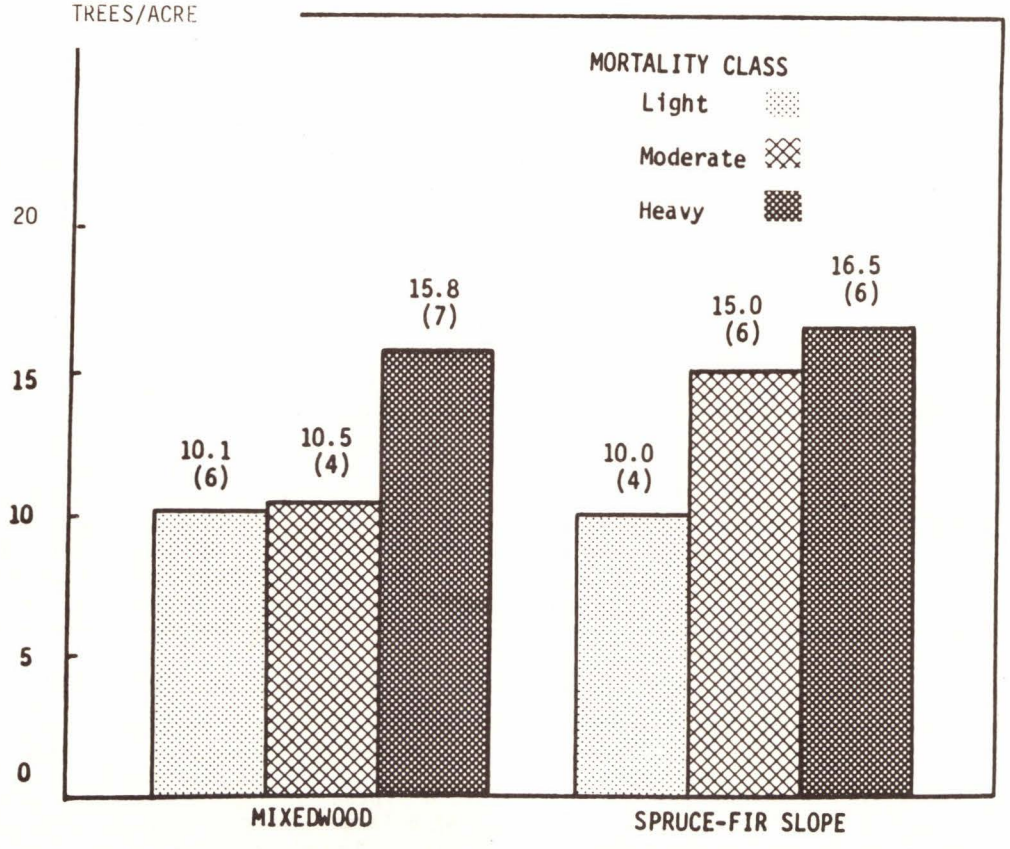

Figure 9.--Standing dead spruce and balsam fir trees 5.0+ inches d.b.h., Vermont Region, 1984, based on photo plot samples (percent standard error in parentheses).

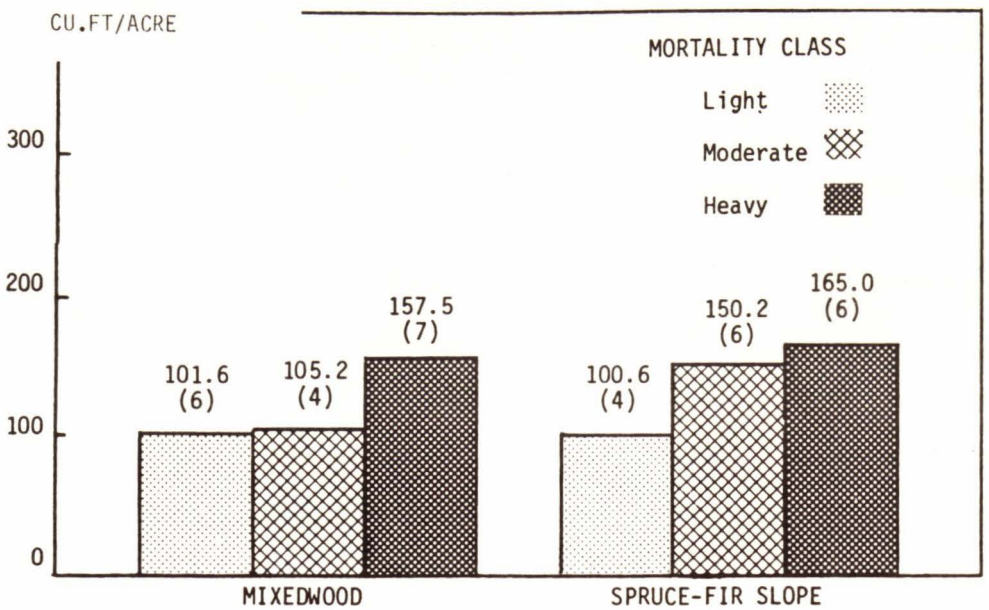

Figure 10.--Standing dead spruce and balsam fir volume for trees 5.0+ inches d.b.h., Vermont Region, 1984, based on photo plot samples (percent standard error in parentheses).

Table 12.--Number of spruce and balsam fir trees (5.0+ inches d.b.h.) per acre, by tree condition, cover type, and mortality class, Vermont Region, 1984 (based on variable-radius plot data)

Tree condition	Spruce-fir slope						Mixedwood					
	Light mortality		Moderate mortality		Heavy mortality		Light mortality		Moderate mortality		Heavy mortality	
	Spruce	Fir	Spruce	Fir	Spruce	Fir	Spruce	Fir	Spruce	Fir	Spruce	Fir
Live trees												
Healthy	63.4	37.6	92.8	35.1	73.6	30.1	40.6	6.8	43.4	27.3	6.7	17.7
Declining[a]												
10-50%	2.0	0	15.2	8.7	20.0	11.0	4.5	0	5.7	1.4	2.4	21.7
> 50%	0	0	1.0	0.8	3.4	3.0	0.6	0	1.5	0.2	2.0	2.5
All live trees	65.4	37.6	109.0	44.6	97.0	44.1	45.7	6.8	50.6	28.9	11.1	41.9
Dead trees												
Recent	1.4	0.6	3.9	1.8	7.3	3.1	1.4	0.6	2.3	0.7	0.8	1.2
Old	1.8	0.4	3.4	3.2	6.7	6.0	2.1	1.6	2.2	0.6	3.2	10.7
Snag	0.4	0.4	2.3	2.2	2.3	9.9	0.5	0	3.8	0.8	0.6	14.4
Windthrown	0	0.7	0.4	1.2	2.7	0	4.2	0	0.2	0	0.1	1.4
All dead trees	3.6	2.1	10.0	8.4	19.0	19.0	8.2	2.2	8.5	2.1	4.7	27.7
All trees	69.0	39.7	119.0	53.0	116.0	63.1	53.9	9.0	59.1	31.0	15.8	69.6

[a] Percentage classes based on proportion of crown displaying symptoms.

mortality class. Declining trees may include suppressed trees. Spruce budworm defoliation was reported in one plot; the defoliated trees are included as declining.

The symptoms most frequently recorded to describe declining trees were small dead branches and loss of foliage from the outside in. These symptoms may be associated with any of a large number of causes. For example, trees injured by drought typically die from the top down and the outside in (Boyce 1961). Branch dieback also may be associated with root diseases such as shoestring root rot caused by Armillaria mellea. Branch and top dieback also may occur as a result of defoliator feeding.

Table 13.--Basal area of spruce and balsam fir trees (5.0+ inches d.b.h.), by tree condition, cover type, and mortality class, Vermont Region, 1984 (based on variable-radius plot data)

Tree condition	Spruce-fir slope						Mixedwood					
	Light mortality		Moderate mortality		Heavy mortality		Light mortality		Moderate mortality		Heavy mortality	
	Spruce	Fir	Spruce	Fir	Spruce	Fir	Spruce	Fir	Spruce	Fir	Spruce	Fir
	Ft^2/acre											
Live trees												
Healthy	22.2	12.6	38.7	12.3	25.9	8.3	12.6	2.0	17.2	9.7	2.3	5.2
Declining[a]												
10-50%	0	0	6.8	3.2	7.5	4.4	1.6	0	2.8	0.4	1.5	7.2
> 50%	0.4	0	0.5	0.4	1.9	1.3	0.2	0	0.4	0.1	0.9	2.0
All live trees	22.6	12.6	46.0	15.9	35.3	14.0	14.4	2.0	20.4	10.2	4.7	14.4
Dead trees												
Recent	1.0	0.4	2.0	0.8	2.4	1.1	0.4	0.2	0.9	0.1	0.2	0.6
Old	0.6	0.2	2.1	1.5	3.7	2.8	0.8	0.4	0.7	0.2	1.8	3.2
Snag	0.4	0.2	0.9	0.9	1.6	3.6	0.4	0	1.2	0.2	0.5	4.3
Windthrown	0	0.4	0.1	0.4	0.5	0	1.0	0	0.1	0	0.2	0.8
All dead trees	2.0	1.2	5.1	3.6	8.2	7.5	2.6	0.6	2.9	0.5	2.7	8.9
All trees	24.6	13.8	51.1	19.5	43.5	21.5	17.0	2.6	23.3	10.7	7.4	23.3

[a] Percentage classes based on proportion of crown displaying symptoms.

In each situation, intensive examination of individual trees is required for diagnosis.

Windthrow.--Windthrown trees were not abundant in the Vermont Region. The highest proportion of trees windthrown was in the mixedwood light-mortality class, where less than 10 percent of spruces were windthrown.

Regeneration

Spruce regeneration was present on an average of 11.6 percent of the milacre plots in the mixedwood light-mortality class, and on 36.3 percent of the milacre plots in the spruce-fir slope heavy-mortality class (Table 14). Overall, commercial species were found in more than half of the milacre plots. Stocking levels increased as the mortality class increased. This indicates that as the older trees die and stands become open, the amount of regeneration increases to fill the vacant space.

Aerial Survey

The Forest Pest Management staff, USDA Forest Service, sketch-mapped spruce and balsam fir mortality on the Green Mountain National Forest, flying at 1,000 feet above the terrain (Fig.11).[9] Tree mortality of up to 10 percent was observed on 5,800 acres. In addition, 2,410 acres had 10 to 30 percent mortality. The latter acreage was distributed among four small areas at high elevations (above 3,500 feet). The mortality observed

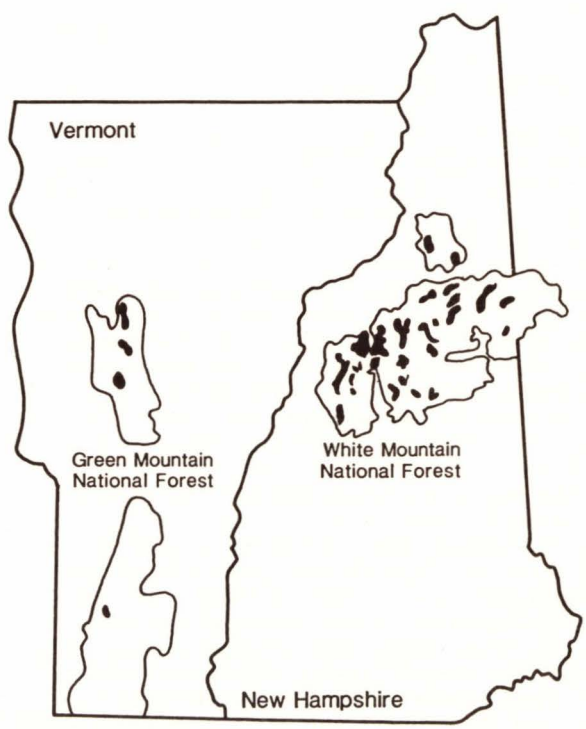

Figure 11.--Areas on Green and White Mountain National Forests where estimated cumulative mortality of spruce and balsam fir exceeds 10 percent(based on 1984 aerial survey).

Table 14.--Regeneration stocking (at least 12 inches tall but less than 5.0 inches d.b.h.), by stocking class, cover type, and mortality class, Vermont region, 1984 (based on milacre plots)

Stocking class	Spruce-fir slope			Mixedwood		
	Light mortality	Moderate mortality	Heavy mortality	Light mortality	Moderate mortality	Heavy mortality
	Percent					
Spruce present	19.6	18.4	36.3	11.6	26.7	19.7
Fir present/spruce absent	11.6	23.5	27.5	8.4	12.5	28.0
Other commercial species only	26.0	13.9	11.5	31.6	18.9	17.5
Total stocked	57.2	55.8	75.3	51.6	58.1	65.2
Nonstocked	42.8	44.3	24.8	48.4	41.9	34.8

included recent and old dead trees as well as snags.

This survey provided an estimate of the proportion of mortality area that occurs on the Green Mountain National Forest. It also confirms that mortality on the Green Mountain National Forest is not extensive, and suggests that most mortality is at the higher elevations.

Regional Summary

In the Vermont Region, spruce-fir cover types were present on 8.3 percent of the area, or about 275,600 acres. Of the spruce-fir area, 43.5 percent (119,900 acres) is mixedwood; 48.1 percent (132,600 acres) is spruce-fir slope; and 8.4 percent (23,100 acres) is spruce-fir swamp. Of the area occupied by spruce-fir cover types less than 10 percent was classified as having heavy mortality. All of the sample plots in the heavy-mortality class were above 2,000 feet in elevation. Heavy-mortality plots were recorded at all aspects, including flat areas.

The region has about 2.7 million dead trees with a volume of 27.5 million ft^3. About 75 percent, were in the large area of light mortality in both the spruce-fir slope and mixedwood types. Most of these trees in the light-mortality class probably represent mortality from causes such as suppression, old age, and chronic insect and disease damage. The highest number of dead trees per acre (16.5) and the highest volume of dead trees per acre (165.0 ft^3) were in the heavy-mortality class of the spruce-fir slope type. Spruce mortality exceeded balsam fir mortality in all but the heavy-mortality classes. In the mixedwood heavy-mortality class, balsam fir mortality was about six times that of spruce mortality.

In the spruce-fir slope type, about 24 percent of live spruce basal area was white spruce, and about 10 percent of dead spruce basal area was white spruce. In the spruce-fir slope type, all of the white spruce mortality was in the light- and moderate-mortality classes; no dead white spruce were found in the heavy-mortality class. In the mixedwood type, only 3 percent of the live and none of the dead spruce was white spruce.

A high percentage of trees were rated healthy. With the exception of the mixedwood heavy-mortality class, the proportion of live spruce rated healthy ranged from 76 to 97 percent. In the mixedwood heavy-mortality class, the proportion of spruce rated healthy was 60 percent and the proportion of balsam fir rated healthy was 42 percent.

In both light-mortality classes, the annual mortality was an estimated 1 to 3 percent, assuming that the recent dead class includes 2 years of mortality. This compares favorably with calculated annual statewide mortality for spruce and balsam fir of 3 to 4 percent in 1972 (Kingsley 1977) and 1 to 2 percent in 1948 (McGuire and Wray 1952).

Spruce and balsam fir regeneration was most abundant where the density of overstory was reduced by mortality. The lowest stocking was in the mixedwood light-mortality class; the highest was in the spruce-fir slope heavy-mortality class. In the latter, average stocking was 36.3 percent spruce and 63.8 percent spruce, fir, or both. About 80 percent stocking is considered satisfactory regeneration in mature stands considered for harvesting.[16]

New Hampshire Region

Forest Cover Area

On the basis of photo stratification of sample blocks, the spruce-fir types occurred on an estimated 363,600 acres (23 percent standard error), or about 16.0 percent of the 2.28 million acres in the New Hampshire Region.

The percentage of the survey region in each cover type is: Mixedwood, 7.6 percent; spruce-fir slope, 7.7 percent; spruce-fir swamp, 0.1 percent; high-elevation balsam fir, 0.6 percent. Of the spruce-fir type, 47.2 percent was classified as mixedwood and 48.2 percent as spruce-fir slope. About 3.9 percent of the total area of spruce-fir type was classified as high-elevation balsam fir; the remaining 0.7 percent was spruce-fir swamp. Figure 12 shows the area by cover type and mortality class for the New Hampshire Region. The total area of spruce-fir type in the survey region represents about one-half of the type in the State. About 314,000 acres of the spruce-fir type in Coos County were not included in the survey region because of spruce budworm damage.

Mortality Area

The estimated area of each mortality class by cover type, as determined from photo stratification of sample blocks, is:

Cover type	No. of acres	Percent standard error of mean
Light-mortality class		
Mixedwood	104,500	24
Spruce-fir slope	73,400	42
Spruce-fir swamp	1,100	76
High-elevation balsam fir	0	0
Total	179,000	22
Moderate-mortality class		
Mixedwood	21,300	22
Spruce-fir slope	25,600	28
Spruce-fir swamp	400	76
High-elevation balsam fir	600	100
Total	47,900	18
Heavy-mortality class		
Mixedwood	45,900	73
Spruce-fir slope	76,300	59
Spruce-fir swamp	900	84
High-elevation balsam fir	13,600	96
Total	136,700	42

About 38 percent of the area of spruce-fir cover types was classified as having heavy mortality. About 27 percent of the mixedwood, 44 percent of spruce-fir slope, and 38 percent of the spruce-fir swamp was classified as having heavy mortality. Almost all of the high-elevation balsam fir type was classified as having heavy mortality.

There were heavy-mortality plots at all elevations. The proportion of these plots increased with elevation. All of the 10 ground plots--6 mixedwood and 4 spruce-fir slope--above 3,000 feet were in the heavy-mortality class. Heavy-mortality plots were found in all aspects.

Inventory of Mortality

On the basis of photo-plot sampling, estimated total mortality in the New Hampshire Region was 5.9 million trees. The total volume was 46.8 million ft^3 (Table 15). The average number of dead spruce and balsam fir trees per acre ranged from 11.6 in light-mortality mixedwood to 27.2 on heavy-mortality spruce-fir slope (Fig. 13). The average cubic-foot volume of dead trees per acre is shown in Figure 14.

Tree Condition

In the spruce-fir slope type, average stocking ranged from 104.5 to 167.9 spruce and from 72.0 to 196.3 balsam fir trees per acre (Table 16). In the mixedwoods, average stocking ranged from 37.1 to 98.2 spruce and from 92.3 to 142.1 balsam fir trees per acre (Table 16). Estimates of basal area are shown in Table 17.

Healthy.--More than half of the live spruce and balsam fir in the spruce-fir slope and mixedwood types were rated as healthy (Table 16).

Dead.--The percentage of spruce dead ranged from 10 in the spruce-fir slope light-mortality class to 32 in the mixedwood heavy-mortality class (Table 16). Dead balsam fir ranged from 14 to 22 percent. The proportion of recently dead trees in both cover types and most mortality classes ranged from 2 to 7 percent; in the mixedwood heavy-mortality class, the average was 14 percent.

Old mortality and snags combined outnumbered recently dead trees in all but one cover type and mortality class. The older dead trees and snags represent cumulative mortality, probably for 10 years or more. Trees rated as recently dead represent at least 2 years of mortality. Many of the dead trees probably are of small diameter.

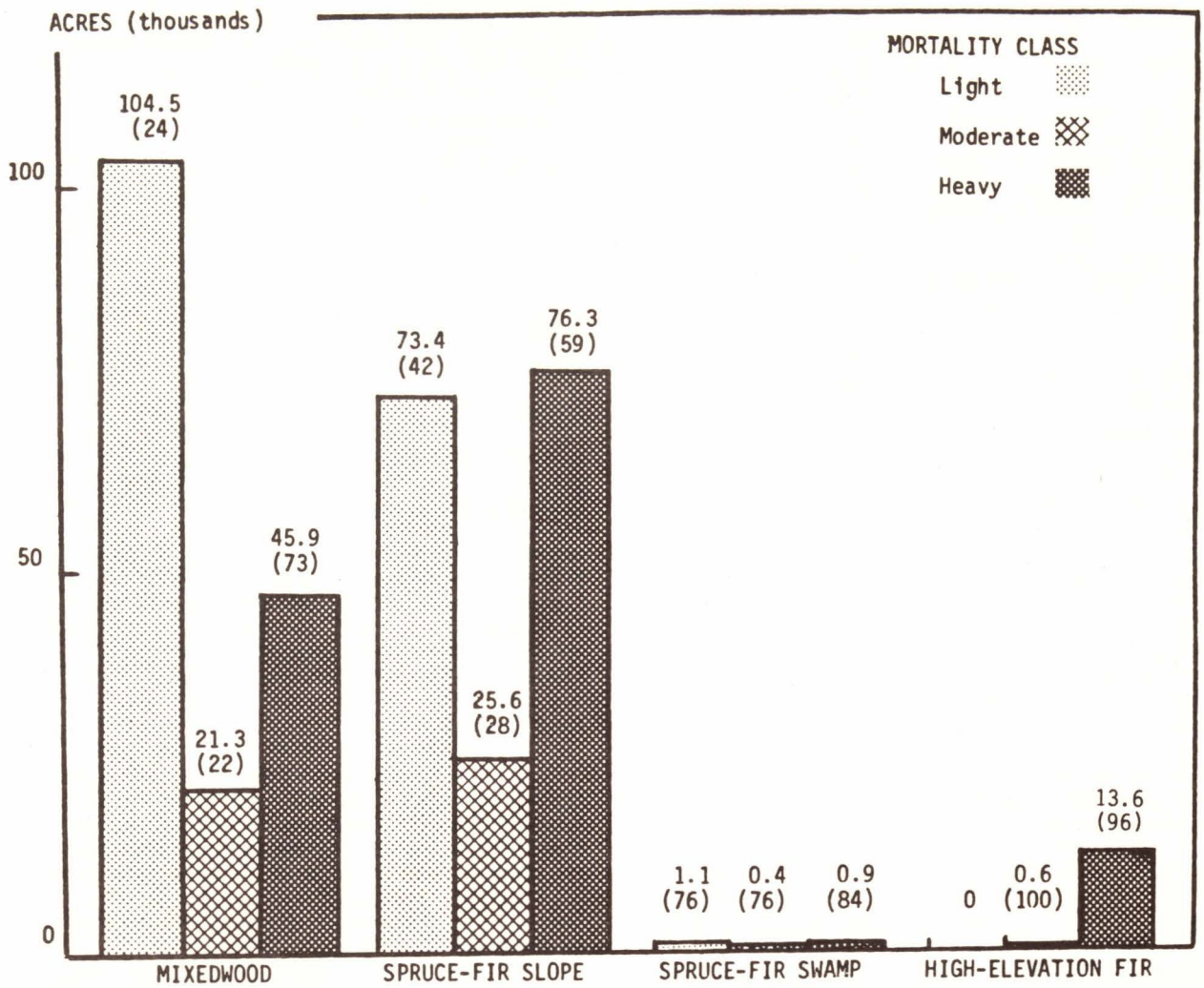

Figure 12.--Area by cover type and mortality class, New Hampshire Region, 1984, based on photo interpretation of sample blocks (percent standard error in parentheses).

Declining.--The highest proportion of live spruce or balsam fir rated 10 to 50 percent declining was spruce in the mixedwood heavy-mortality class (39 percent), and in the spruce-fir slope heavy mortality class (25 percent) (Table 16). The proportion of spruce in the 50 percent or more declining class was largest in the mixedwood moderate-mortality class (21 percent).

The symptoms most frequently recorded to describe declining trees were small dead branches, large dead branches, and loss of foliage from the outside in. These symptoms may be associated with any of a large number of causes. For example, trees injured by drought typically die from the top down and the outside in (Boyce 1961). Branch dieback also may be associated with root diseases such as shoestring root rot caused by Armillaria mellea. Branch and top dieback also may result from defoliator feeding. In each situation, intensive examination of individual trees is required for diagnosis.

Windthrow.--Windthrown trees were present in all cover types and mortality classes (Table 16). The highest number of windthrown trees, 6.8 trees per acre, was in the mixedwood light-mortality class.

Table 15.--Number and gross volume of standing dead spruce and balsam fir trees (5.0+ inches d.b.h.), by cover type and mortality class, New Hampshire Region, 1984 (based on photo-plot samples)

Cover type	Mortality class	Number of dead trees	Volume of dead trees
			Ft^3
Mixedwood	Light	1,210,000 (25)[a]	10,300,000 (25)
	Moderate	300,000 (22)	2,420,000 (22)
	Heavy	890,000 (73)	7,010,000 (73)
	All classes	2,400,000 (30)	19,730,000 (29)
Spruce-fir slope	Light	950,000 (42)	7,890,000 (42)
	Moderate	420,000 (28)	3,380,000 (28)
	Heavy	2,080,000 (59)	15,760,000 (59)
	All classes	3,450,000 (37)	27,030,000 (37)
Both cover types		5,850,000 (25)	46,760,000 (24)

[a] Percent standard error in parentheses.

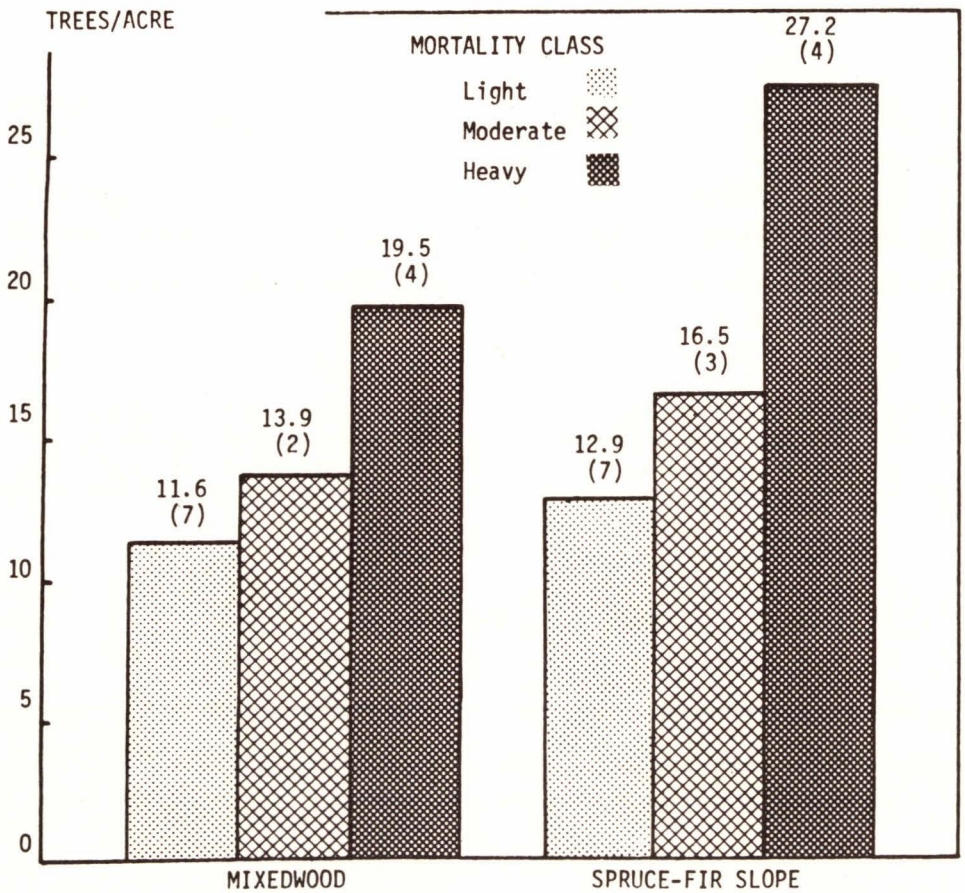

Figure 13.--Standing dead spruce and balsam fir trees 5.0+ inches d.b.h., New Hampshire Region, 1984, based on photo plot samples (percent standard error in parentheses).

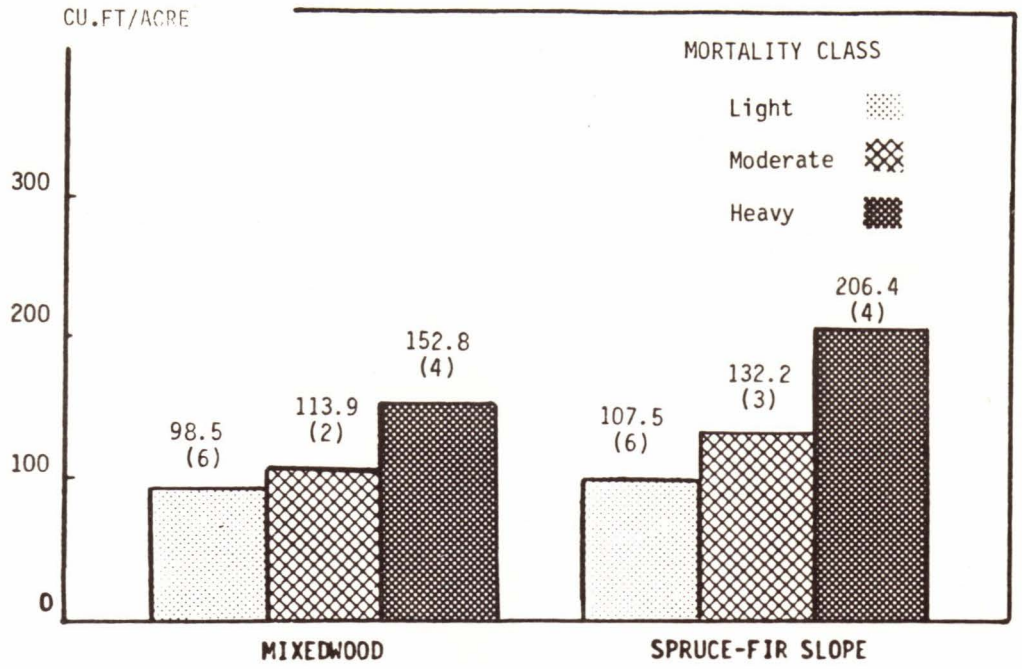

Figure 14.--Standing dead spruce and balsam fir volume for trees 5.0+ inches d.b.h., New Hampshire Region, 1984, based on photo plot samples (percent standard error in parentheses).

Table 16.--Number of spruce and balsam fir trees (5.0+ inches d.b.h.) per acre, by tree condition, cover type, and mortality class, New Hampshire Region, 1984 (based on variable-radius plot data)

Tree condition	Spruce-fir Slope						Mixedwood					
	Light mortality		Moderate mortality		Heavy mortality		Light mortality		Moderate mortality		Heavy mortality	
	Spruce	Fir	Spruce	Fir	Spruce	Fir	Spruce	Fir	Spruce	Fir	Spruce	Fir
Live trees												
Healthy	136.1	73.8	74.5	52.6	54.1	124.5	67.3	87.0	15.8	62.1	17.2	100.9
Declining[a]												
10-50%	13.0	16.3	28.5	4.3	19.4	25.3	15.4	9.8	9.3	14.7	13.3	14.0
> 50%	1.4	0	14.6	0	5.5	3.5	0.9	1.0	6.7	1.0	3.6	2.3
All live trees	150.5	90.1	117.6	56.9	79.0	153.3	83.6	97.8	31.8	77.8	34.1	117.2
Dead trees												
Recent	7.6	3.7	7.6	5.8	5.5	8.4	5.0	2.2	1.9	2.9	6.9	9.4
Old	6.8	3.1	3.0	2.9	9.1	1.8	2.7	3.0	1.8	5.3	6.1	5.3
Snag	3.0	4.5	2.1	4.3	9.4	30.2	2.0	8.4	1.1	5.9	1.9	8.3
Windthrown	0	3.2	1.9	2.1	1.5	2.6	4.9	1.9	0.5	0.4	0.9	1.9
All dead trees	17.4	14.5	14.6	15.1	25.5	43.0	14.6	15.5	5.3	14.5	15.8	24.9
All trees	167.9	104.6	132.2	72.0	104.5	196.3	98.2	113.3	37.1	92.3	49.9	142.1

[a] Percentage classes based on proportion of crown displaying symptoms.

Table 17.--Basal area of spruce and balsam fir trees (5.0+ inches d.b.h.), by tree condition, cover type, and mortality class, New Hampshire Region, 1984 (based on variable-radius plot data)

Tree condition	Spruce-fir slope						Mixedwood					
	Light mortality		Moderate mortality		Heavy mortality		Light mortality		Moderate mortality		Heavy mortality	
	Spruce	Fir	Spruce	Fir	Spruce	Fir	Spruce	Fir	Spruce	Fir	Spruce	Fir
	Ft^2/acre											
Live trees												
Healthy	46.0	22.6	28.7	14.0	22.7	38.2	29.6	27.8	8.0	18.8	6.5	35.3
Declining[a]												
10-50%	5.0	5.0	10.0	1.1	10.2	5.8	5.0	3.0	5.0	4.6	5.6	4.9
> 50%	0.4	0	7.0	0	2.2	0.9	0.4	0.2	3.3	0.6	1.3	0.9
All live trees	51.4	27.6	45.7	15.1	35.1	44.9	35.0	31.0	16.3	24.0	13.4	41.1
Dead trees												
Recent	2.0	1.6	2.4	1.9	2.9	2.6	1.8	0.8	1.0	1.0	2.4	2.7
Old	2.2	1.2	1.0	1.1	4.0	0.4	1.2	0.8	2.0	2.3	1.7	2.0
Snag	0.8	1.0	1.1	1.6	4.4	9.6	0.8	2.2	1.0	3.3	1.5	2.6
Windthrown	0	1.4	1.0	0.8	0.4	0.9	1.4	0.8	0.5	0.6	0.4	1.1
All dead trees	5.0	5.2	5.5	5.4	11.7	13.5	5.2	4.6	4.5	7.2	6.0	8.4
All trees	56.4	32.8	51.2	20.5	46.8	58.4	40.2	35.6	20.8	31.2	19.4	49.5

[a] Percentage classes based on proportion of crown displaying symptoms.

Regeneration

Spruce regeneration was present on an average of 27.6 to 53.3 percent of the milacre plots (Table 18). Spruce stocking increased as the mortality class increased in both the spruce-fir slope and mixedwood types. This indicates that as the trees die and stand overstory opens, the amount of spruce regeneration increases. Stocking appears to be adequate in all situations.

Aerial Survey

Aerial sketch-mapping of spruce and balsam fir mortality was carried out on the White Mountain National Forest in New Hampshire.[5] The Forest Pest Management staff, USDA Forest Service, surveyed the Forest on June 28, 1984. Tree mortality of up to 10 percent was observed on 16,000 acres. In addition, 6,500 acres had more than 30 percent mortality, and 57,000 acres had between 10 and 30 percent mortality

Table 18.--Regeneration stocking (at least 12 inches tall but less than 5.0 inches d.b.h.), by stocking class, cover type, and mortality class, New Hampshire Region, 1984 (based on milacre plots)

Stocking class	Spruce-fir slope			Mixedwood		
	Light mortality	Moderate mortality	Heavy mortality	Light mortality	Moderate mortality	Heavy mortality
	Percent					
Spruce present	30.0	39.4	53.3	27.6	36.5	42.8
Fir present/spruce absent	32.4	21.7	28.4	37.2	40.0	36.0
Other commercial species only	10.4	12.3	4.4	9.2	8.5	12.6
Total stocked	72.8	73.4	86.1	74.0	85.0	91.4
Nonstocked	27.2	26.6	13.9	26.0	15.0	8.6

(Fig. 11). Almost all of the areas with more than 30 percent mortality were above 3,500 feet. About 60 percent of the areas with 10 to 30 percent mortality were above 3,500 feet in elevation. The mortality observed included recent and old dead trees as well as snags. The survey provided an estimate of the proportion of mortality area that occurs on the White Mountain National Forest.

Regional Summary

In the New Hampshire Region, spruce-fir types occupy 16.0 percent of the area, or about 363,600 acres. Of the spruce-fir area, 47.2 percent (171,700 acres) is mixedwood, 48.2 percent (175,300 acres) is spruce-fir slope; 0.7 percent (2,400 acres) is spruce-fir swamp; and 3.9 percent (14,200 acres) is high-elevation balsam fir. About 38 percent of the total area of spruce-fir types was classified as having heavy mortality. Mortality was heavy on about 27 percent of the mixedwood type, 44 percent of spruce-fir slope, 38 percent of the spruce-fir swamp, and nearly all of the high-elevation balsam fir type. Heavy mortality was found at all elevations and all aspects.

In the region, there are an estimated 5.9 million dead trees with a volume of 46.8 million ft^3. Stocking levels of spruce and balsam fir are comparatively high, ranging from an average of 104.5 to 167.9 spruce trees and from 72.0 to 196.3 balsam fir trees per acre on the spruce-fir slope type. The highest number of dead trees per acre (27.2) and the highest volume of dead trees per acre (206.4 ft^3) were in the spruce-fir slope heavy-mortality class. Much of the mortality in all mortality classes may be caused by suppression, chronic insect and disease problems, and old age.

The proportion of live spruce rated healthy ranged from 63 to 90 percent with the exception of the mixedwood moderate-mortality and mixedwood heavy-mortality classes where 50 percent of the spruce were rated healthy. The proportion of balsam fir rated healthy ranged from 80 to 92 percent.

The percentage of trees rated recently dead ranged from 2 to 7. Assuming that one-half of the recently dead trees per acre represent mortality for 1 year, our estimates indicate 1 to 3.5 percent annual mortality. This compares with estimates from forest survey inventories of 0.9 percent in 1960 (Ferguson and Jensen 1963) and 0.2 to 0.3 percent in 1972 (Kingsley 1976). However, direct comparison with forest survey data in New Hampshire may not be valid since our survey, unlike forest inventory surveys, included a large proportion of the non-commercial high-elevation forest.

Spruce regeneration was most abundant where the density of the overstory was reduced by mortality. In the heavy-mortality areas, spruce stocking exceeded 40 percent.

Interpreting the Data

Averages

The regional averages include both commercial and noncommercial forest land and describe a wide range of stand and tree conditions not normally found in surveys of commercial forests. This range of conditions is related to differences in stand composition and tree size that vary with forest age, elevation, soils, and past land use.

Mortality Classes

The mortality classes used in the survey do not necessarily indicate increasing rates of current mortality or the extent of any abnormal conditions. The assumption was that about 10 percent standing dead trees represent a normal forest condition. One to three percent annual mortality has been recorded in inventories of commercial forests in New York, Vermont, and New Hampshire since the 1940's. This mortality is due to such factors as competition and chronic insect and disease damage. Dead trees usually remain standing for 5 years or longer. Therefore, 10 percent cumulative mortality can be considered the normal condition. In high-elevation noncommercial forests, many of which were included in the survey, normal cumulative mortality may be considerably greater than 10 percent because the rate at which dead trees deteriorate there is slower than at lower elevations. There may be other situations where trees deteriorate more slowly. Therefore, the moderate and heavy mortality classes may or may not represent abnormal conditions. Additional examination is needed to determine the significance of the mortality.

Annual Mortality Rate

Our estimates of annual mortality are based on the persistence of fine twigs on dead trees. The "recent dead" class is assumed to indicate a 2-year cumulative mortality, and one-half of that mortality is our calculated annual mortality. If the rate of branch deterioration is higher or lower, then the annual mortality rate would be different.

Tree Decline Classes

The decline classes used in this survey included trees that appeared to have damaged or abnormal crowns, regardless of the kind of damage, stand, tree and site factors, or cause. Normal forest processes result in "declining" symptoms. A suppressed red spruce may exhibit foliage loss and poor growth for many years, but, once the overstory is removed, regain its vigor and lose these symptoms (Curry and Church 1952; Murphy 1917; Pinchot 1898). Likewise, damage from freezing, insects, or wind may create a temporary declining condition from which a tree recovers. The spruce and balsam fir growing at high elevations could be rated as severely declining for most of their

growth, since that may be the best possible condition they can achieve under the adverse conditions. In areas where tree condition ratings were poor, long-term evaluation is needed to determine if a trend exists.

Causes of Mortality

Determination of cause or causes in specific situations was not an objective of the survey. However, to ensure that known factors were considered in interpreting the survey results, historical records were searched. In addition, Forest Pest Management entomologists and pathologists examined several areas in or near sample plots. Their examinations suggest the need to examine the role of root diseases and root damage from wind. Only readily identifiable damage agents were recorded during the survey. Detailed examination of stands in a variety of situations will be needed to determine the role of all known factors. For example, areas of high balsam fir mortality should be examined for root disease, since these diseases are known to be serious in this species.

Trends and Correlations

Data were collected that are not presented in this report. Analysis of possible correlations of mortality with elevation, aspect, stand, and site conditions may require collection of additional data. Where possible, further analysis of these data will be made and the results presented in future reports. Trends are difficult to establish from a single survey. Changes in mortality rates or in area of mortality need to be determined over a period of time.

Other Limitations of the Survey

The survey was not designed to provide the location of all areas of moderate or heavy mortality. Location of mortality was determined in sample blocks only. Because both commercial and noncommercial areas were included in the survey regions, and because an undetermined amount of the mortality is normal, economic losses are not as great as might be indicated by the data alone. Assessment of economic loss will not be possible without additional work.

The data presented are estimates for each region and are based on samples. The precision of most of the estimates is described by a sampling error. The estimates are most precise at the survey region level. They are not necessarily applicable to a smaller unit. The survey was not designed to provide estimates for specific ownerships or management units.

The predominant spruce in both the spruce-fir slope and mixedwood types was red spruce. White spruce and black spruce were minor components except in Vermont, where white spruce made up about 18 percent of the live spruce basal area and 6 percent of the dead spruce basal area.

Determining the cause or causes in areas of moderate and heavy mortality was not an objective of the survey. However, historical records of mortality and major mortality factors were reviewed. Detailed examination of specific situations will be needed to determine the incidence of historically significant insects and diseases, and the extent to which they are responsible for the mortality observed.

SUMMARY

Mortality Area

The extent of mortality varied among regions (Table 19). These differences probably are related to forest age, soil, and elevation. Intensive examination is needed of areas classified as having moderate or heavy mortality to determine what factors may be involved and to what extent the mortality may be considered normal. Average annual mortality from competition and chronic insect and disease damage is 1 to 3 percent for commercial forests. Therefore, about 10 percent standing mortality can be considered normal. Many high-elevation, noncommercial stands were included in the survey; and in these stands, normal cumulative mortality may be higher than 10 percent because the rate of deterioration of dead trees is slower than at lower elevations.

Dead and Declining Trees

The number of standing dead spruce per acre (excluding snags) ranged from 3.2 to 17.7, with the highest in the spruce-fir slope moderate-mortality class of the Adirondack Region (Table 20). The number of standing dead balsam fir per acre (excluding snags) ranged from 1.0 to 19.1, with the highest in the spruce-fir slope light-mortality class of the Tug Hill Region (Table 20).

The percentage of standing dead spruce per acre (excluding snags) ranged from 6.1 to 26.1, with the highest in the mixedwood heavy-mortality class of the New Hampshire Region (Table 20). The percentage of standing dead balsam fir per acre (excluding snags) ranged from 2.5 to 24.4, with the highest in the mixedwood light-mortality class of the Vermont Region. Areas with high percentages of trees dead need to be examined intensively for all factors that could lead to higher mortality.

The highest proportion of live spruce trees rated as declining occurred at Tug Hill (74 to 98 percent). The proportion of live spruce rated as declining in other regions were Adirondack, 30 to 54 percent; Vermont, 3 to 40 percent; and New Hampshire 10 to 50 percent. In general, the proportion of balsam fir rated as declining was less than that for spruce, but did exceed spruce in several instances.

Regeneration Stocking

Except in Tug Hill, regeneration stocking was highest in the heavy-mortality classes, indicating that as overstory trees die, the stands are being restocked. Areas with heavy mortality need to be examined periodically to determine the long-term success of established regeneration.

Spruce regeneration stocking, in most cases, was most abundant in the heavy-mortality classes; the highest was in the Adirondack mixedwood (75 percent) and spruce-fir slope (66 percent); and New Hampshire mixedwood (43 percent) and spruce-fir slope (53 percent). Spruce regeneration was lowest in Tug Hill, where stocking ranged from 5 to 17 percent. The proportion of milacre plots nonstocked was highest in Vermont (25 to 48 percent) and Tug Hill (35 to 42 percent).

Historical Records

Historical records were searched for previous reports of mortality and causes. Competition and chronic insect and disease damage have caused mortality annually. Several other factors have been reported causing damage

Table 19.--Summary of the area of spruce-fir cover types, by region and mortality class, 1984 (based on photo interpretation of sample blocks)

		Adirondack		Tug Hill		Vermont		New Hampshire	
Cover type	Mortality class	Number of acres	Percent of cover type	Number of acres	Percent of cover type	Number of acres	Percent of cover type	Number of acres	Percent of cover type
Mixedwood	Light	254,600	56	10,900	82	99,000	83	104,500	61
	Moderate	149,700	33	2,200	16	17,000	14	21,300	12
	Heavy	50,500	11	200	2	3,900	3	45,900	27
Spruce-fir slope	Light	86,500	41	9,100	100	103,000	78	73,400	42
	Moderate	65,400	31	0	0	17,200	13	25,600	15
	Heavy	58,100	28	0	0	12,400	9	76,300	43
Spruce-fir swamp	Light	118,900	53	500	72	9,200	40	1,100	46
	Moderate	73,900	33	100	14	8,000	35	400	17
	Heavy	31,600	14	100	14	5,900	25	900	37
High-elevation balsam fir	Light	0	0	0	0	0	0	0	0
	Moderate	0	0	0	0	0	0	600	4
	Heavy	0	0	0	0	0	0	13,600	96

Table 20.--Standing dead spruce and balsam fir (excluding snags) per acre, by cover type, mortality class, and region, 1984 (based on variable-radius plot data)

	Spruce-fir slope						Mixedwood					
	Light mortality		Moderate mortality		Heavy mortality		Light mortality		Moderate mortality		Light mortality	
Region	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
						SPRUCE						
Adirondack	5.6	6.8	17.7	18.6	14.9	15.8	7.1	12.3	3.3	8.6	10.5	16.9
Tug Hill	3.4	13.4	--	--	--	--	9.6	15.0	5.7	10.4	6.6	11.4
Vermont	3.2	4.6	7.3	6.1	14.0	12.1	3.5	6.5	4.5	7.6	4.0	25.3
New Hampshire	14.4	8.6	10.6	8.0	14.6	14.0	7.7	7.8	3.7	10.0	13.0	26.1
						BALSAM FIR						
Adirondack	4.8	8.2	4.1	6.7	3.4	5.8	3.6	10.0	3.7	9.0	1.5	6.3
Tug Hill	19.1	14.9	--	--	--	--	11.9	11.2	11.5	9.6	9.3	17.7
Vermont	1.0	2.5	5.0	9.4	9.1	14.4	2.2	24.4	1.3	4.2	11.9	17.1
New Hampshire	6.8	6.5	8.7	12.1	10.2	5.2	5.2	4.6	8.2	8.9	14.7	10.3

and mortality in one or more of the regions in recent years:

At high elevations:

- Wind, ice, and snow
- Winter desiccation
- Drought
- Overmature stand conditions
- Fluctuations in water level

At low elevations:

- Drought
- Winter desiccation
- The spruce beetle (spruce more than 10 inches d.b.h.)
- Root diseases
- Fluctuations in water level

Change in climate is another factor that has been discussed in relation to tree mortality at both high and low elevations. Air pollution also has been suggested as a factor that may be involved.

The spruce budworm has been a serious problem in recent years in northern New Hampshire and northeastern Vermont. Areas known to have spruce budworm damage were not included in the survey.

Recommendations

Forest Pest Management surveys and evaluations are recommended to determine:

- The major relationships between mortality and a large range of site and stand conditions.
- The role of historically significant insects and diseases in areas of moderate to heavy mortality.
- Increases in the extent and rate of mortality.
- The location of areas on state and private lands where mortality is occurring.
- The precise delineation and classification of mortality areas on the National Forests.
- The economic impact of the moderate and heavy mortality.

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